AN UNCONFINED COMPRESSION TESTING MACHINE FOR MARINE SEDIMENTS

by

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THESIS

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September 1970

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
September 1970

ABSTRACT

The two most common laboratory test methods used for measuring the undisturbed or original shear strength of marine sediments are the vane shear test and the unconfined compression test. The application of the load in the unconfined compression test is accomplished either in a strain-controlled or a stress-controlled manner. An unconfined compression testing machine was constructed to allow application of the load by either the strain-controlled or stress-controlled method, and it was specifically designed to accurately test marine sediments having relatively low values of shear strength. A unique feature of the apparatus is that it provides a continuous plot of displacement versus load throughout the test procedure. Tests for shear strength in the two load application modes were conducted on gravity cores taken on the continental slope between San Francisco and Monterey. Results of the tests compared favorable with each other, as well as with values secured from vane shear testing. The tests suggest that these particular sediments have friction angles approximating 30 degrees.

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ACKNOWLEDGEMENTS

The author wishes to thank Dr. Raymond J. Smith, Professor of Oceanography, Naval Postgraduate School, for his advice and encouragement in the development of this machine. Appreciation is also expressed to the Machine Facility, the Photographic Department, and to Miss Georgia Galloway for secretarial assistance. The author is also grateful for the interest and support provided by the Naval Facilities Engineering Command. Finally, the author is indebted to his wife Dianne for her continued patience and understanding during the period of postgraduate studies.

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I. INTRODUCTION

GENERAL

An effort has been made in recent years to determine more about the mass physical properties of the sediments present on the ocean floor. Both private industry and governmental agencies have contributed greatly to these programs. It is necessary that much more be accomplished along these lines, particularly as to the quantity and quality of the data obtained from areas deeper than the continental shelf.

One of the chief physical properties of marine sediments that is often measured is its shear strength. The two most commonly used tests to determine this are the vane shear and the unconfined compression tests. A vane shear apparatus was built by Minugh (1970) and modified by Heck (in press) to specifically measure the vane shear strength of these soft marine sediments. An unconfined compression testing machine has also been designed and constructed to accurately measure sediment shear strength by use of either the strain-controlled or stress-controlled mode of loading, and it is described herein. A brief summary of marine sediment structure, shear strength theory and the unconfined compression test are presented in the following sections.

MARINE SEDIMENT STRUCTURE

Most of the marine sediments found on the ocean floor in water greater than continental shelf depth consist primarily of either (Keller, 1968):

1. Extremely fine-grained inorganic pelagic clays.

2. Calcareous ooze consisting of at least 30 percent calcium carbonate tests.

3. Siliceous ooze consisting of at least 30 percent siliceous material formed from diatom and radiolarian debris.

The marine clays vary considerable in coloration. In that they are primarily composed of minerals which tend toward basal cleavage, the clay particles are either terraced platelets or rod-shaped in appearance. Such shapes offer a large amount of surface area which is important in considering the nature of sediment strength. Both calcareous and siliceous planktonic skeletons similarly have relatively large surface areas and generally have disc or elongated shapes.

The fine-grained soil particles tend to flocculate or form loose-knit aggregations in settling to the sea floor. Rod-shaped or elongated particles are visualized as forming a random "match-stick" structure, causing the sediment to have high values of shear strength due to an interlocking of particles in all directions. Flocculated platelet-shaped particles characterized by edge-to-face contact between adjacent particles initially retain their flocculent structure unless disturbed. This is the result of a large osmotic pressure being created between the platelet faces. This osmotic pressure apparently results from the attraction of negative ions to these faces, which in turn repel each other and keep face-to-face contacts to a minimum. There is some evidence that a slight positive charge exists on the platelet edges. Such a structure is very weak and unstable, and any disturbance such as a shearing force or sediment compression causes the angle between the platelets to be reduced. Since the repulsive force varies inversely with platelet spacing, the platelets become parallel and separated from each other resulting in a more stable and stronger structure characterized by the solid platelets being dispersed in a continuous liquid matrix (Hough, 1969).

SHEAR STRENGTH THEORY

The shearing strength of a material is its ability to withstand shearing stresses. When a maximum resistance is exceeded, slippage occurs resulting in failure. In most natural materials the shearing strength is made up of both an internal friction, a resistance due to physical contact between the particles, and a cohesion. The cohesion represents the strength not due to friction, and its exact nature and source is not well known.

The concept of shear strength has its beginning with the classical Coulomb equation:

$$s = c + p \tan \phi$$

where

s = Shearing strength.

c = Cohesion.

p = Normal stress.

ϕ = Angle of internal friction.

In soils, Terzaghi's statement of the principle of effective stress in which the pore water pressure is subtracted from the normal stress to give an effective normal stress modifies the Coulomb equation to:

$s = c + (p-u) \tan \phi$ or

$s = c + p' \tan \phi$

where

u = Pore water pressure.

p' = Effective normal stress.

Solid friction is generally considered to be negligible between particles in saturated marine sediments when they are stressed in an undrained manner with no loss of pore water (Keller, 1968), and therefore the angle

of internal friction is taken to be equal to zero. In such a case, the shear strength of the sediment is equal to its cohesion.

A simple and rapid laboratory test to measure the shear strength of a cohesive sediment is the unconfined compression test. The simplicity of the test makes it one of the most widely used tests conducted on cohesive sediments. Furthermore, though it requires removal of the sediment sample from its core liner prior to testing, this mode of testing provides excellent shear strength data for experimental and comparison purposes.

UNCONFINED COMPRESSION TEST

General

The unconfined compression test measures the compressive strength of a cylindrical sediment sample. It does not require any lateral support due to its cohesion. On the Mohr circle diagram shown in Figure 1, shear strength AB is equal to BC cos Ø, or

$$\tau = BC \cos \phi = \frac{\sigma_1}{2} \cos \phi$$

For a friction angle of 30 degrees, the shear strength would be approximately $0.433\sigma_1$, where σ_1 is the major principal stress. Precise measurements have established that a lower value of strength is inherently obtained in the unconfined compression test compared to results from other techniques. This may result from the fact that no lateral support is given to the sample during testing. Shear strength is generally taken to be one-half the major principal stress (Lambe, 1951). This corresponds to the assumption that for marine sediments the angle of internal friction is zero.

The unconfined compression test is usually conducted at the natural water content of the "in-situ" sample, and efforts are made to minimize the

Mohr Circle Diagram

of the

Unconfined Compression

Test

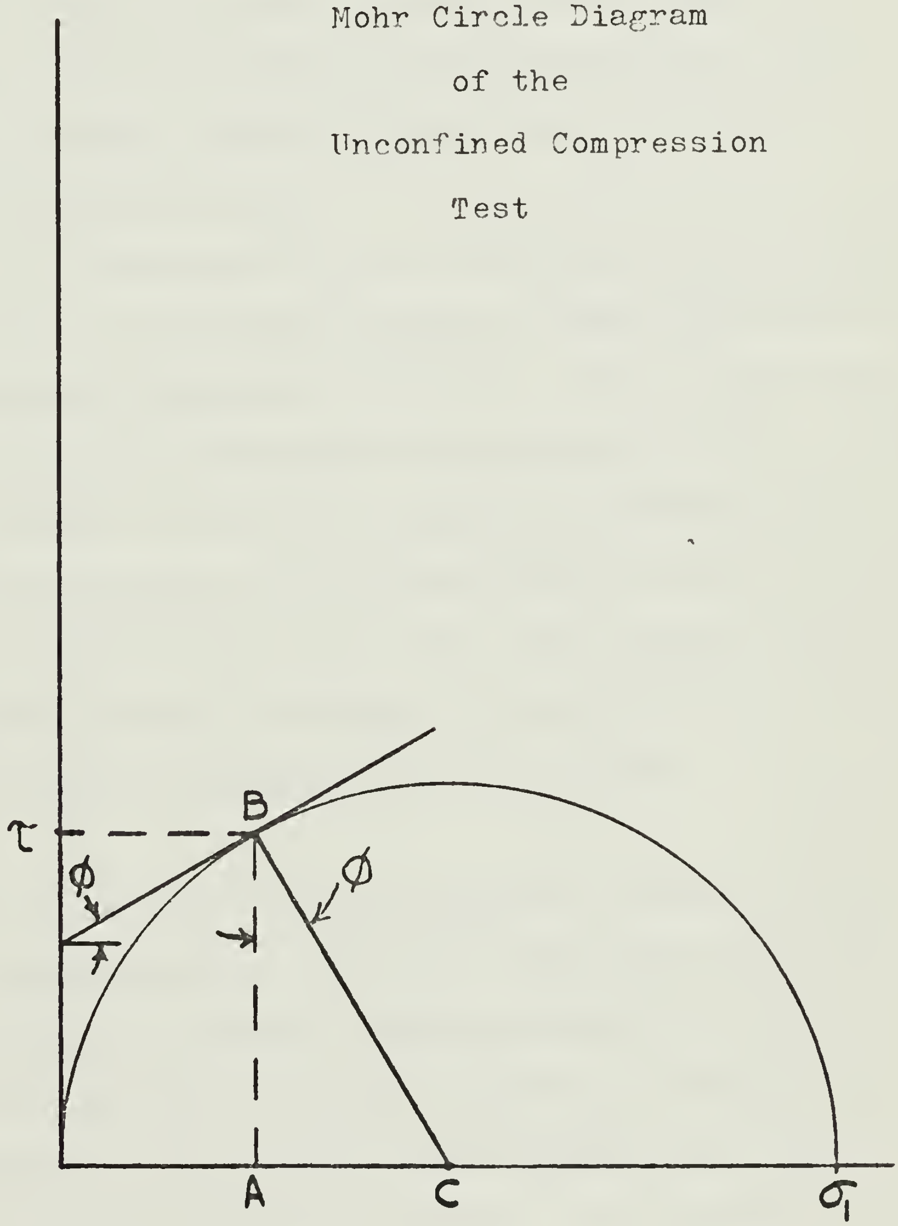


Figure 1.

time the sample is exposed to normal humidities to prevent surface drying. Although slight drainage occurs on the exposed sides of the sample, the effect is negligible and the test is considered to be undrained.

The two major advantages of this test over the direct shear test are that more uniform stresses and strains are imposed and that the failure plane occurs at the weakest portion of the sample and is not forced to occur along a predetermined surface.

This test has two advantages over use of the triaxial test when dealing with marine sediments. It is quick and simple and offers less opportunity for sample disturbance during testing preparations. This is particularly the case when handling marine sediments having low values of shear strength. If the sediment strength is too low, the samples lack sufficient coherence to permit their being tested in the unconfined mode and either the triaxial or preferably the vane shear test must be made. The following sections describe recommended apparatus, procedures, and calculations to be used when conducting unconfined compression tests (ASTM, 1964).

Apparatus

Compressing the sample may be accomplished with a hydraulic loading device, an air loading apparatus, a deadweight load system or any other compressive technique with sufficient capacity and control to provide a rate of loading of one-half to two percent per minute of controlled axial strain or application of 1/10 to 1/15 of the estimated failure load every 30 seconds using the controlled stress procedure. For unconfined compressive stresses in the range less than 13.9 pounds per square foot, the device should be capable of measuring the unit load to at least 0.139 pounds per square foot.

The displacement indicator should measure to an accuracy of 0.001 inches, with a range of travel at least 20 percent of the sample height. A vernier caliper should also be available to assist in measuring the physical dimensions of the sample to the nearest 0.01 inches.

The moisture content of the sample should be measured with a drying oven with thermostatic controls at a temperature at 110 plus or minus five degrees Centigrade. A balance accurate to 0.01 grams should be available.

A timing device accurate to the nearest second is needed to determine both the rate of strain and the time increments for load application.

Controlled Strain Procedure

In making a controlled strain test, the sample is placed on the loading device in the center of the bottom platen and the upper platen is carefully positioned so that it just makes contact with the sample. The displacement indicator is then recorded or zeroed. The load application is adjusted to produce an axial strain rate of one-half to two percent per minute. Load and displacement values are recorded at least every 30 seconds. The rate of strain should be regulated so that sample failure occurs within a ten minute period. For the weaker marine sediments the greater rate of strain may be used. Loading is continued until either the load decreases with increasing strain or a 20 percent strain is reached. The moisture content of the sample is determined and a sketch of the sample made showing the angle of the failure plane.

Controlled Stress Procedure

In the controlled stress procedure an estimate is made of the load required to cause failure. The sample is then placed on the center of the loading device bottom platen. The upper platen is carefully positioned so that it just contacts the sample and the displacement indicator is then

recorded or zeroed. An initial load equal to 1/10 to 1/15 the estimated failure load is placed on the sample. After 30 seconds the displacement indicator is read and a second load equal to the first is added. Load increments are added at 30 second intervals and sample displacement is recorded prior to each load application. The procedure is continued until either the sample fails or the 20 percent strain limit is reached. The moisture content of the sample is measured and a sketch of the sample is made.

Calculations

The axial strain, ϵ, is computed as follows:

$$\epsilon = \frac{\Delta H}{H_o}$$

where

ΔH = Change in sample height for a given load.

H_o = Initial sample height.

Using this value for axial strain the average cross-sectional area, A, for a given load is determined from:

$$A = \frac{A_o}{1-\epsilon}$$

where

A_o = Initial sample cross-sectional area

The unit shear strength is calculated from:

$$\tau = \frac{P}{2A}$$

where

P = Given applied load.

A = Corresponding cross-sectional area.

A plot is made of unit shear strength versus the corresponding axial strain. The maximum unit shear strength on this curve, or the unit shear strength at 20 percent strain, whichever occurs first, is considered as the shear strength value.

II. DESIGN CONSIDERATIONS

GENERAL

Numerous unique problems are encountered in the design of an unconfined compression testing machine for use specifically for low strength marine sediments. A method must be devised to measure the load applied to the sample in the range of values expected to cause shearing. The displacement must be precisely measured during compression. The device should be capable of conducting both strain-controlled and stress-controlled tests if it is to be useful for research-type efforts in the laboratory. The machine should also have the capability of varying such test parameters as the strain rate, load increments, and range of displacement. The following sections outline some of the factors which were considered in the selection of the major components of the Naval Postgraduate School (NPS) unconfined compression testing machine as constructed.

FORCE TRANSDUCER

One of the most important components of the apparatus is the device which measures the applied load. Most such test machines are equipped with either a proving ring, a hydraulic oil pressure gage, an air pressure gage, or a scale which measures the compressive load being placed on the sample. Some stress-controlled devices simply use the value of the known weight increment and assume that this entire weight is transmitted to the sample (Richards, 1961). To accurately determine the values of load applied directly to the sample in the extremely low range of 0 to 50 pounds, a force transducer was considered the most satisfactory and economical device. The transducer chosen has a weighing platform on which the sample is placed during the test, and this allows consideration of the effects that

the sample weight might have in the shear strength determination. Losses occurring due to friction, torque variations, and vibrations are accounted for, since any directly applied static or dynamic force is precisely measured.

A transducer produces an electrical output signal which is amplified and sent to an X-Y recorder. This provides a permanent load record and eliminates the necessity for reading and recording load values during the test.

DISPLACEMENT TRANSDUCER

The second major measuring device used on the unconfined compression testing machine as designed is the displacement transducer. A dial indicator is used on most machines to detect sample displacement, and this requires the operator to regularly read and record the displacement value. This evolution is usually combined with the reading of a timer and the simultaneous reading and recording of the load value. Time lags occur between these steps and operator errors are introduced because the dials are being read and the values are being recorded. These time lags and operator errors are eliminated by use of a displacement transducer, as it produces a continuous electrical output signal of the precise value of the displacement. The plot of this signal provides a permanent record which can be used to extract values of displacement at any sample height. A complete record of what occurs throughout the test is considered superior to a point-to-point faired curve, and this represents the prime reason that a displacement transducer was selected to measure sample displacement

VARIABLE SPEED MOTOR, CONTROLLER AND JACTUATOR

It is desirable to have a load transmission device which encompasses

the range of load expected during testing and allows the rate of load application to be varied. An off-the-shelf reduction gear, which reduces the driving force speed to the extremely slow strain rates required by the unconfined compression test, should be obtained. This eliminates the need to manufacture these components locally. Every attempt should be made to use precision gears so as to eliminate vibrations being transmitted from the driving force to the sample. Allowance for variation of the strain rates must also be considered. Hand cranks and constant speed motors do not allow changes in output shaft speed unless gearing is changed. This usually leads to additional costs and alignment problems. A variable speed DC motor with its own control circuitry is ideal for rotating at constant speed over the full range of rated torque. These types of motors and controls can be readily obtained in the speed and torque ranges necessary for the testing of marine sediments.

RECORDING OF LOAD AND DISPLACEMENT

The obtaining of a permanent record in the form of a continuous graph of load versus sample displacement represented the main design goal of this unconfined compression testing machine. This eliminates the need for an operator to periodically read and record values of load and displacement, and further permits examination of the entire test profile. Vibrations, variations in torque transmission, frictional losses, and the shear microstructure of the sample can be detected. Equipment malfunctions, observable as deviations from normally expected recordings, can be corrected prior to test continuation.

POWER SUPPLY

Electrical and electronic components of the unconfined compression

testing machine should be self-contained in the regulating, rectifying and transforming of their own power supplies. Each component must be capable of being powered from the normally available 115 volt, 60 Hertz, grounded supply. Overload and short-circuit protection should be integral parts of these components.

STRUCTURAL COMPONENTS

A lightweight, sturdy machine fabricated from relatively inexpensive corrosion resistant materials is a major design consideration. Availability of both materials and machining facilities must also be considered. Although not meant to be portable, the unconfined compression testing machine should be light enough in weight to facilitate movement around the laboratory. A sturdy platform should be provided for the machine components to eliminate any transmission of vibrations from either surrounding equipment or the motor of the machine itself.

BALL BUSHING

The loss due to friction of load transmission in the stress-controlled mode of testing should be kept to a minimum. This insures that the preselected weight increment is fully transmitted to the sediment sample. A friction-free bushing should be considered when selecting the guiding device for the shaft.

III. NPS UNCONFINED COMPRESSION TESTING MACHINE

GENERAL DESCRIPTION

The NPS unconfined compression testing machine is intended primarily for laboratory use. It was designed specifically to conduct unconfined compression tests on low strength marine sediments by either strain-controlled or stress-controlled methods. Allowance was made to facilitate variation of such factors as range of displacement, loading increment, and strain rate for future use.

The machine may be configured for either the strain-controlled mode shown in Figure 2, or the stress-controlled mode shown in Figure 3. In either configuration the amplifier-indicators and X-Y recorder of Figure 4 are used to respectively amplify and record the load and displacement signals from the machine. This feature provides a permanent record of precisely what occurred to the sample during the test. An accurate value of the sediment shear strength can be computed from this record.

The components of the NPS unconfined compression machine are as follows:

1. Force transducer
2. Displacement transducer
3. Transducer amplifier-indicators
4. Machine screw jactuator
5. Variable speed motor
6. Motor speed controller
7. Structural components
    a. Base
    b. Lower platform
    c. Support columns
    d. Upper platform
8. Displacement transducer support bracket
9. Jactuator shaft upper platen
10. Jactuator spacer
11. Shaft extension arms
12. Weighted piston assembly
    a. Weight holder
    b. Weighted piston shaft
    c. Upper platen

Figure 2. The NPS Unconfined Compression Testing Machine in the Strain-Controlled Mode

Figure 3. The NPS Unconfined Compression Testing Machine in the Stress-Controlled Mode

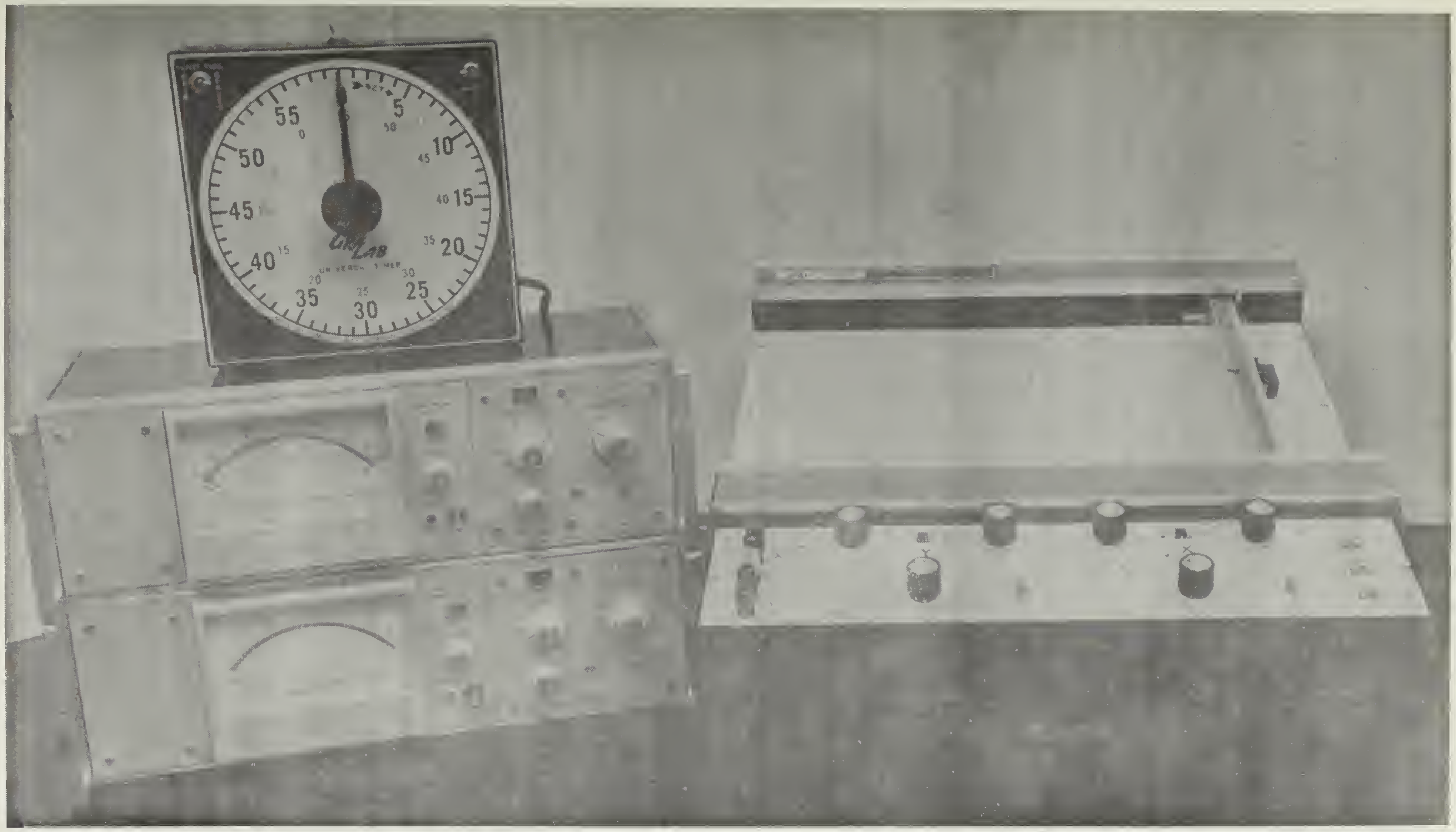


Figure 4. The Model 300D Amplifier-Indicators and the X-Y Recorder

13. Lead discs
14. Ball bushing and pillow block

The components, except for items number 1 through 6 and number 14, were fabricated by the Machine Facility at the Naval Postgraduate School. A detailed description of each of these components is given in the following sections.

FORCE TRANSDUCER

The force transducer shown in Figure 5 is a Series 152 A transducer manufactured by the Daytronic Corporation of Dayton, Ohio. Its range is from 0 to 50 pounds, which allows sediment shear strengths of up to 6.6 pounds per square inch to be measured assuming 2¼-inch diameter samples. This maximum capacity encompasses most shear strength values expected in deep-ocean marine sediments.

The transducer produces an electrical output proportional to any applied force or weight. The linearity is 0.2 percent of the transducer range, while repeatability is 0.1 percent of range. The sensitivity is five millivolts per volt for rated force at a frequency of 400 Hertz. The deflection of a dual diaphragm spring, integrally machined from alloy steel, is measured by a sensitive differential transformer element. This particular type of mechanical design provides rigid lateral probe stability so as to eliminate errors from side-thrust or non-symmetrical loading. No bearings, pivots or sliding contacts are incorporated in the transducer, hence it is not subject to friction errors or wear and provides excellent resolution, repeatability and long life without hysteresis.

Precision internal construction plus temperature compensation minimize any zero shift due to temperature changes and allows the use of only 0.005 inches of deflection stroke for full load. The maximum design temperature

Figure 5. The Force Transducer and the Displacement Transducer

shift of zero or sensitivity is 0.02 percent of range per degree Fahrenheit. The ambient temperature range of the transducer is minus 65 to plus 200 degrees Fahrenheit.

Since the system has a high natural frequency, dynamic as well as static loads can be measured. These dynamic measurements are feasible up to approximately 20 percent of the natural frequency of the spring-mass system comprised of the transducer and the supported inertial mass. The natural frequency (in Hertz) is approximately

$$F = 50\sqrt{\frac{L}{0.1 + W}}$$

where

L = Nominal rated load of transducer, in pounds.

W = Weight of supported inertial mass, in pounds.

There are mechanical safety stops at either end of travel to prevent shift of calibration or damage from overloading. The safe load capacity of the transducer is 150 pounds. Epoxy encapsulation and magnetic shielding of the differential transformer element protects the transducer from moisture, corrosive atmospheres and external electrical interference.

The transducer receives its power supply from a Model 300D Transducer Amplifier-Indicator and sends its output signal to the Type 70 Input Module mounted within the amplifier. A type 22S shielded cable with amphenol connectors joins the amplifier and the transducer. Excitation frequency ranges from 400 to 10,000 Hertz with a voltage range from two to ten volts.

The force transducer is attached to the lower platform of the unconfined compression testing machine by four mounting bolts through four ¼-inch holes in its 3 9/16-inch diameter base. With its weighing platform installed the transducer is three inches in height. The weighing platform, which easily screws

into a ¼ inch-28 threaded connection on the top of the transducer, is made of aluminum and is 3½ inches in diameter. The sediment sample, which is 2¼ inches in diameter, is conveniently placed in the center of the weighing platform. Once the sample is in place, the force transducer continuously measures not only the weight of the sample but any applied static or dynamic force. This measured signal is electrically amplified and sent to an X-Y recorder where it is displayed on the Y-axis.

DISPLACEMENT TRANSDUCER

The displacement transducer shown in Figure 5 is a Model DS 2000 also manufactured by the Daytronic Corporation. This provides a continuous output signal voltage which is exactly proportional to the mechanical displacement of the sensing probe. The linear range of displacement of the transducer is plus or minus one inch and its linearity is within 1.0 percent of calibrated range. Transducer sensitivity is 50 millivolts per volt for full scale displacement at a frequency of 60 Hertz.

The transducer consists of a primary coil and two secondary coils arranged symmetrically to form a hollow cylinder. A small magnetic iron core, supported by a non-magnetic rod, is positioned to move axially within the cylinder in response to the mechanical input to the sensing probe. When the primary coil is excited by a source of alternating current, and the core is in the center or null position, the AC voltages induced in the secondary coils are equal due to the symmetry of coupling between the primary and secondary coils. The secondary coils are connected in series such that they oppose each other, hence the induced voltages will cancel in the null position and there will be no net output voltage. When the core is displaced axially, one secondary voltage will increase while the other decreases, and a net

output signal voltage is produced which is proportional to the magnitude of displacement from the null position. The phase polarity corresponds to the direction of displacement from the null position. The output signal voltage is sent via a Type 22S shielded cable to a Model 300 D Transducer Amplifier-Indicator with a Type 70 Input Module. This phase sensitive carrier amplifier-indicator provides the greatest accuracy and sensitivity possible for a differential transformer system.

The coils in the displacement transducer are encapsulated in epoxy, magnetically shielded and solidly mounted in metal housings. Since the transducer operates on inductance effects, there are no sliding contacts or flexing wires. Because of these construction features, the transducer does not develop noise or open circuits and is extremely resistant to vibrations, humidity, corrosive atmospheres, and electrical interference. The transducer is designed to minimize errors from temperature shift of both the zero and sensitivity controls. The ambient temperature range is minus 65 degrees Fahrenheit to plus 200 degrees Fahrenheit.

The transducer has an overall length of 12 7/8 inches and a diameter of 7/8 inches. The top of the transducer is provided with a 1½-inch long, 3/4 inch-16 thread such that a locking nut screws on and rigidly secures the transducer to its mounting bracket in a vertical position. The up-down motions of the jactuator and weighted piston shafts are mechanically transmitted to the transducer end probe so that the precise position of the upper platen of the compression machine is continuously measured, electrically amplified, and displayed on the X-axis of an X-Y recorder.

TRANSDUCER AMPLIFIER-INDICATOR

The transducer amplifier-indicator shown in Figure 4 is a Model 300 D

also manufactured by the Daytronic Corporation. It is a highly sensitive, solid-state, stabilized, carrier amplifier with a precision indicating meter. It is completely compatible with and specifically designed to provide power and receive and amplify signals from either the force transducer or the displacement transducer. Two amplifier-indicators are used in conjunction with the unconfined compression testing machine so that both force and displacement signals are continuously received, amplified, and sent to an X-Y recorder.

The transducer amplifier-indicator comes with a standard recorder output which has an adjustable 5 to 55 millivolt range for full scale output. Its accuracy is 0.2 percent of the scale for the range on which it is calibrated and this accuracy includes effects of line voltage variation, plus or minus 15 degrees Fahrenheit room temperature variation, and 30 days drift. The meter output accuracy is 0.5 percent of scale under similar conditions. The standard meter is six inches, zero on the left, 100 scale divisions, and scales of 0-20, 0-50, and 0-100 and is equipped with a reversing switch. Transducer excitation is approximately three volts at 3000 Hertz.

A Type 70 Input Module is used on both amplifier-indicators. This unit provides nulling, phasing, zeroing, and calibration adjustments. These adjustments can be accomplished in a quick and precise manner. The range selector on this unit offers seven calibrated sensitivity ranges from plus or minus 0.1 inches full scale to plus or minus 0.001 inches full scale. Provisions are included for operation at multiples of these ranges for longer stroke measurements. A Transducer Conditioning Selector Switch changes circuit values in the null control, zero control, and phase compensation circuits so as to match the electrical characteristics of the transducer selected. For the 0 to 50 pound force transducer, Position B on the Transducer Conditioning Selector Switch is selected and Position 1 on the Range Selector

Switch is used in order to give full scale deflection for ten pounds of force. This gives a meter accuracy of 0.05 pounds and a recorder output accuracy of 0.02 pounds force. The displacement transducer requires the Transducer Conditioning Selector Switch to be in Position D and the Range Selector Switch in Position 100. This gives full scale defection for 0.5 inches of displacement. Thus an accuracy of 0.0025 inches is obtained on the meter and a recorder output accuracy of 0.001 inches is achieved.

The zero control on the module is used to supplement the transducer mechanical zero adjust or position. The force transducer mechanical zero adjust is set by the manufacturer but, if nulling can not be accomplished, a set screw adjustment is provided on the central shaft of the transducer. This set screw is held in its proper null position by another locking screw above it and the adjustment is difficult to make. The mechanical zero for the displacement transducer is the zero position of the end probe necessary to accomplish nulling of the amplifier. Once nulled, both transducers use the zero control for precise adjustment of the system zero even at high sensitivities.

The null control for the module provides compensation for quadrature signal voltages arising from cable capacitance and other sources. Adjustment is quickly accomplished and remains fixed for a given transducer installation.

The module CAL REFERENCE Control adjusts an internal signal source so as to simulate the connected transducer at a known value of load or displacement. This source can then be used as a reference standard which allows rapid checking of calibration at any time.

The power requirements for the amplifier-indicator are 105 to 130 volts, 50 to 400 Hertz, and ten watts. The unit has standard bench mount dimensions

of $5\frac{1}{4}$ inches high, 17 inches wide, and $9\frac{1}{2}$ inches deep. Both the input and output modules are the plug-in, sliding contact type which allow easy removal for maintenance. One amplifier-indicator is placed on top of the other and conveniently located next to the X-Y recorder to facilitate monitoring of meter indications during testing.

MACHINE SCREW JACTUATOR

The machine screw jactuator is a Model KM-2500-18 manufactured by the Duff-Norton Company of Charlotte, North Carolina. This unit has a one ton capacity and is used as the driving shaft for the upper platen on the unconfined compression testing machine in the strain-controlled mode. A variable speed motor connects to and drives the $\frac{1}{2}$-inch, keyed worm gear input shaft on the jactuator. The worm gear has a standard ratio of five to one which moves the keyed output shaft one inch for every 25 turns of the worm input shaft. The rated torque at full load is 55 inch-pounds. The jactuator can be controlled exactly for positioning in thousandths of an inch, and its self-locking feature will hold the load in position without creep.

The output shaft diameter is 3/4 inches and its length is 18 inches. At the load end of the output shaft a $\frac{1}{2}$ inch-13-UNC-2A threaded connection, 3/4 of an inch in length, is provided so that the upper platen can be screwed onto the shaft. Since the output shaft is keyed, no rotation of the shaft and upper platen occurs.

The closed height of the jactuator is $4\frac{1}{2}$ inches and its base size is 2 3/4 x 5 inches. The base is secured to the upper platform of the unconfined compression machine by means of two, 3/8-inch diameter bolts. An aluminum spacer $1\frac{1}{2}$ inches in height is placed between the jactuator base and the upper platform so that proper alignment between the jactuator input shaft and the motor drive shaft is achieved.

VARIABLE SPEED MOTOR

The electric motor used to drive the jactuator is a Type NHS-34RJ manufactured by the Bodine Electric Company of Chicago, Illinois. It is a shunt wound, 115 volt DC, ball bearing electric motor rated at 1/15 horsepower. The motor is rated for continuous duty and may be reversed either while stopped or running. Starting torque for the motor is approximately 150 percent for full load torque. There are ball bearings on the motor armature and in the gear head. Its rated ratio is 300 to 1 and rated speed is 5.7 revolutions per minute.

The overall dimensions of the motor and its gear box is 11 5/8 inches long, 6 7/8 high, and approximately eight inches wide. The 3/4-inch diameter, keyed output shaft of the motor is connected to the jactuator input shaft by means of a rigid coupling. The motor base is bolted to the upper platform of the unconfined compression testing machine by four 3/8-inch bolts.

MOTOR SPEED CONTROLLER

The Minarik Electric Company of Los Angeles, California, manufactures the motor speed controller for the variable speed motor. This controller is specifically designed to operate the Bodine shunt wound motor used on the unconfined compression testing machine and is the Model W-33. This particular controller offers excellent regulation, line voltage compensation and torque control characteristics. A Speed Range Switch on the controller allows selection of either a low or high speed range. In the LO Position the speed of the motor output shaft can be varied from 0.22 to 6.8 revolutions per minute at a constant torque of 219 inch-pounds. The output shaft speed can be varied from 0.22 to 10 revolutions per minute at a constant

torque of 118 inch-pounds when the HI Position is used. The speed is controlled with a potentiometer mounted with an easily read dial. For a testing strain rate of two percent per minute, the Speed Range Switch is placed in the LO Position and the Speed Control Potentiometer is set on 41. The motor speed can be preset or changed as desired whether the motor is running or stopped. The controller has a Forward-Brake-Reverse Switch so that the motor may be instantly started and stopped at any speed setting under full load. The switch can be left in the Brake Position indefinitely without overheating the motor.

The controller is made for either 115 or 230 volts AC, 50/60 Hertz input and converts this to the necessary DC voltage, with feedback, for motor regulation when a changing load or line voltage condition exists. A silicon controlled rectifier is used for half-wave armature supply. The field supply is full-wave. A choke-capacitor filtering system provides a better form-factor which allows a lower motor temperature under constant use, continuous duty over the entire speed range at rated motor torque, and elimination of inter-com noise. Dependable solid state circuitry is used in the controller which provides instant operation and longer life.

The controller is provided with a rugged metal case and a six foot grounded power supply cable. Key holes on the side of the case allow it to be easily mounted or removed from the side of the upper platform of the unconfined compression testing machine. To facilitate testing, the controller is mounted at the right hand front of the upper platform by means of two screws. A socket on the back of the controller case accepts the amphenol connector of the five foot motor cable. A fuse protects the controller against transient voltages, short circuits and motor overloads.

X-Y RECORDER

The X-Y Recorder used during this particular test program was a Honeywell Model 540. Any quality recorder is however acceptable. The recorder used should preferably have a one millivolt/division scale and should be capable of utilizing a 16.5 x 11-inch piece of graph paper with a ten division per inch scale.

STRUCTURAL COMPONENTS

The structural components of the unconfined compression testing machine consist of the base, lower platform, upper platform and support columns. These components have been designed to provide a sturdy, vibrationless structure upon which to mount the other components. Aluminum was selected as the material for the base and the upper and lower platforms because it is lightweight, strong and corrosion resistant. Stainless steel was used for the columns because of its strength and corrosion properties, and because of its ready availability. The overall dimensions of the assembled structural components are 24 inches wide, 26 3/4 inches high and 18 inches deep.

The base shown in Figure 6 was fabricated from two-inch thick aluminum plate to provide a solid machine foundation. Eight threaded holes have been made in the base, four for the support columns and the others to bolt down the lower platform.

The details of one of the support columns are also shown in Figure 6. The length of these columns was chosen to provide a height of two feet between the base and the upper platform. This is to allow easy access to the weighing platform when handling the sediment sample. Each column screws into the base, and the top threaded portion of the column penetrates a

hole in the upper platform such that weight of the upper platform is supported by a lip on the column. A nut is then screwed on to the threaded portion of the column securing the upper platform to the column. The sturdiness of the columns proved sufficient to eliminate any vibrations caused by motor rotation.

Shown in Figure 7 is the lower platform. It is fabricated from 3/8-inch aluminum plate welded to form a five-sided hollow box open at the bottom. Two brackets are welded on both the front and back permitting it to be bolted to the base. The holes in the brackets are large enough to allow adjustment of the lower platform so as to insure that the weighing platform is centered beneath the upper platen. An access hole in the back of the lower platform facilitates disconnecting the amphenol connector on the displacement transducer and unbolting the force transducer base and displacement transducer support bracket. There are seven holes in the platform top. Two of these are for displacement transducer support bracket bolts and four are used to hold the force transducer bolts. The seventh hole allows sufficient space for housing the displacement transducer.

The upper platform, shown in Figure 8, was fabricated from 3/4-inch aluminum plate and supports the electric motor, jactuator, jactuator spacer, and the ball bushing. Four holes are provided for mounting the motor, two holes for mounting the jactuator and jactuator spacer, and two holes for securing the ball bushing. A large hole allows the passage of either the jactuator output shaft or the weighted piston shaft. The four additional holes, previously noted, are for the support columns.

DISPLACEMENT TRANSDUCER SUPPORT BRACKET

The displacement transducer support bracket of Figure 9 bolts to the

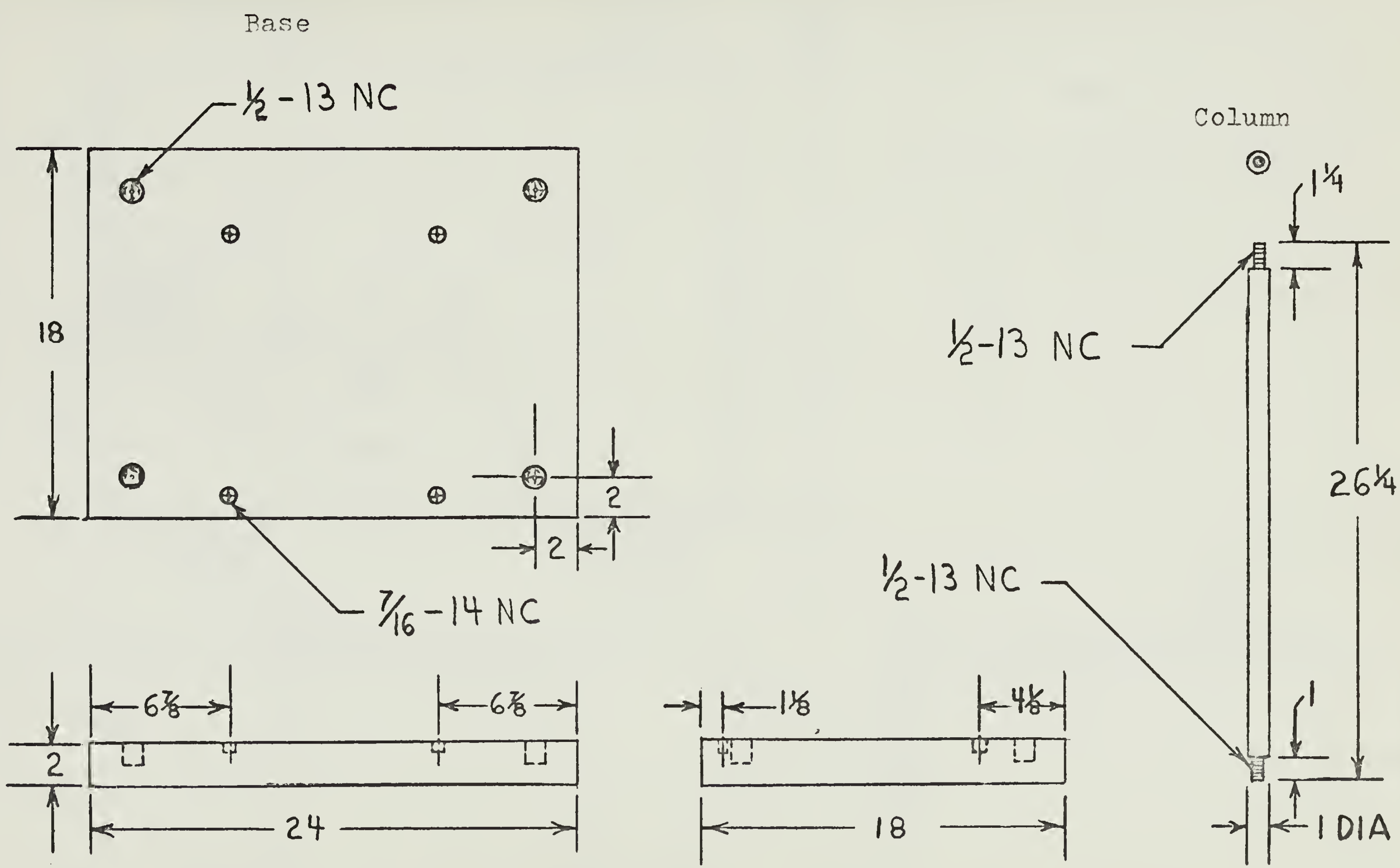


Figure 6. Detail of the Base and the Support Columns

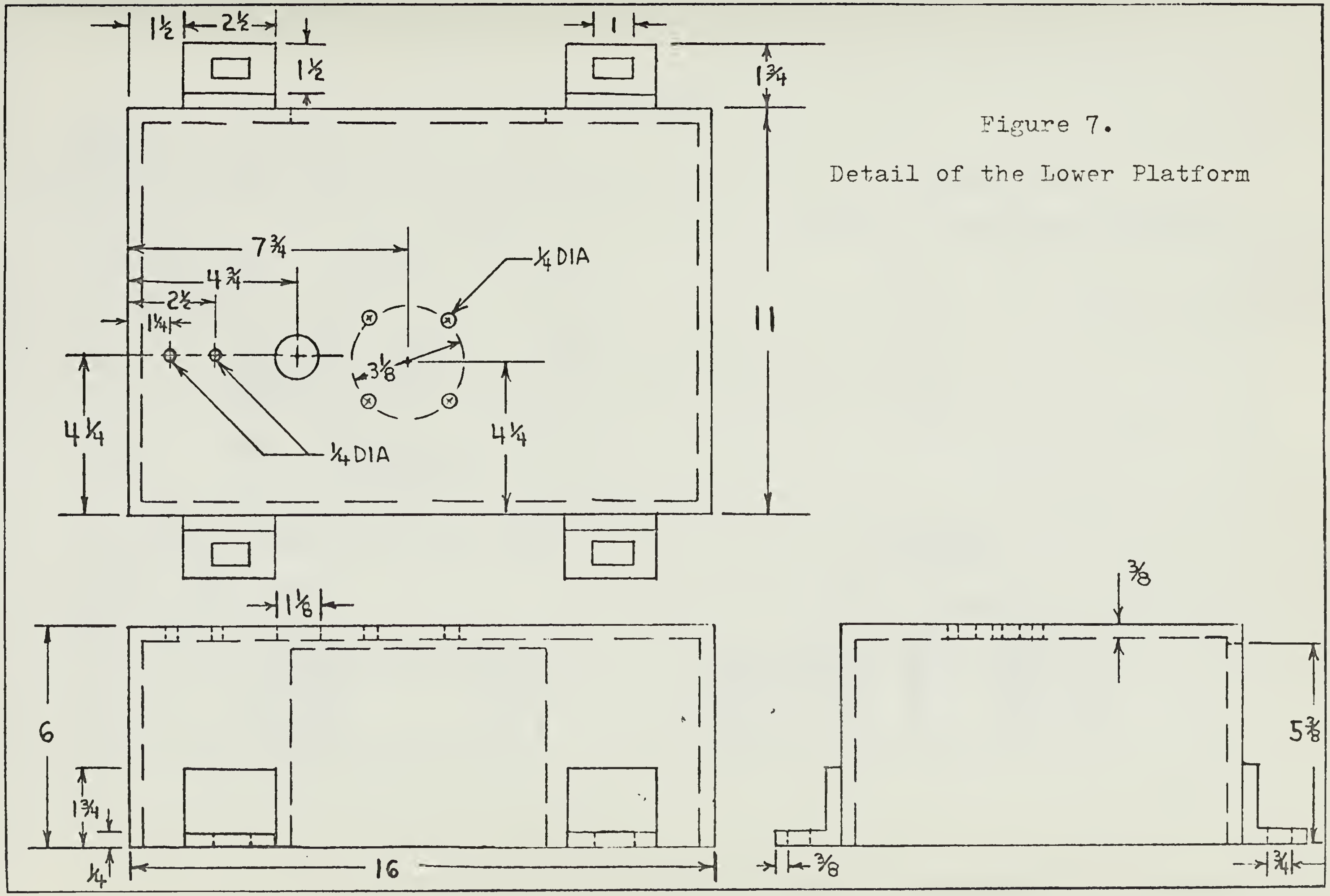


Figure 7.

Detail of the Lower Platform

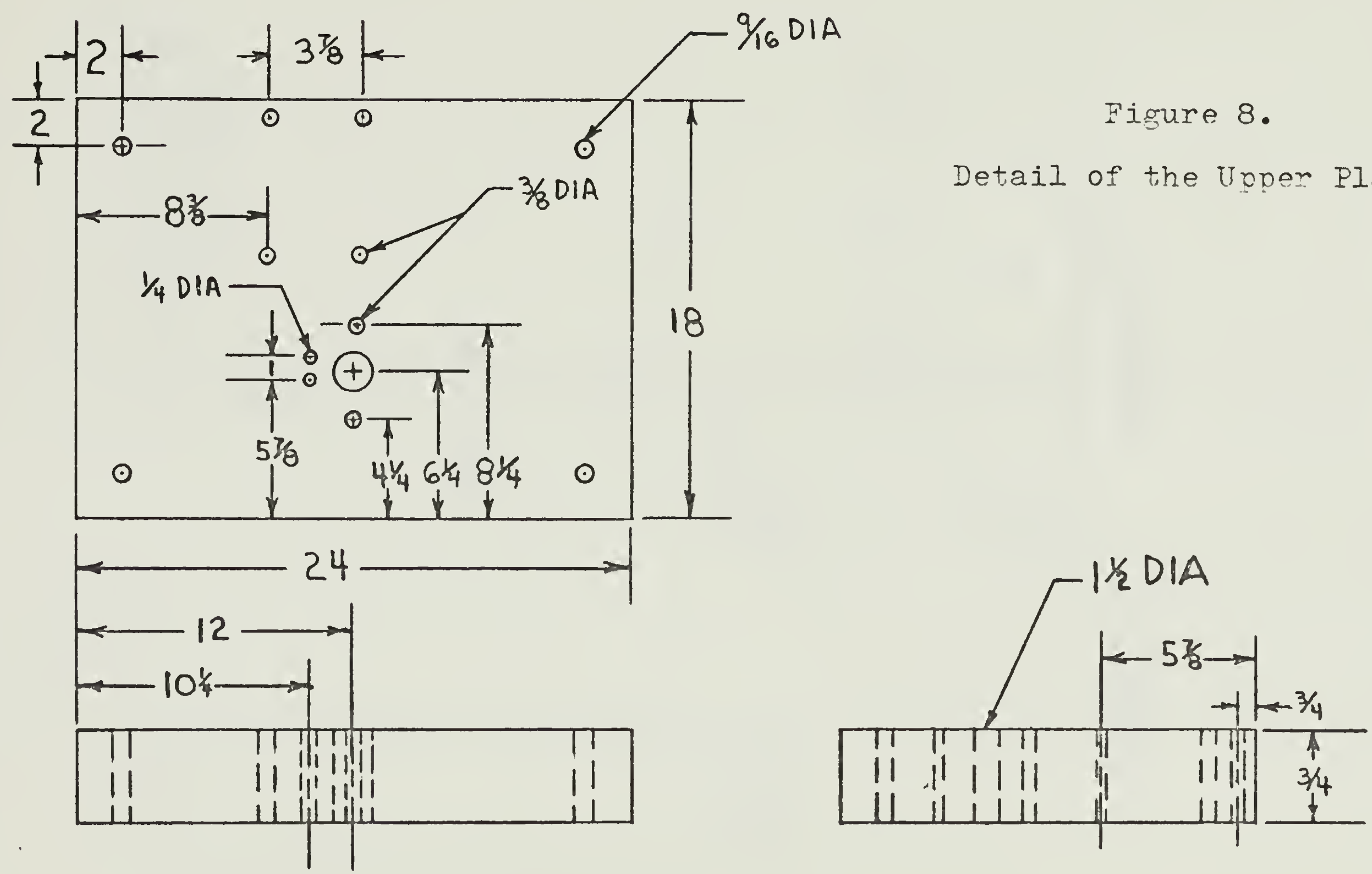
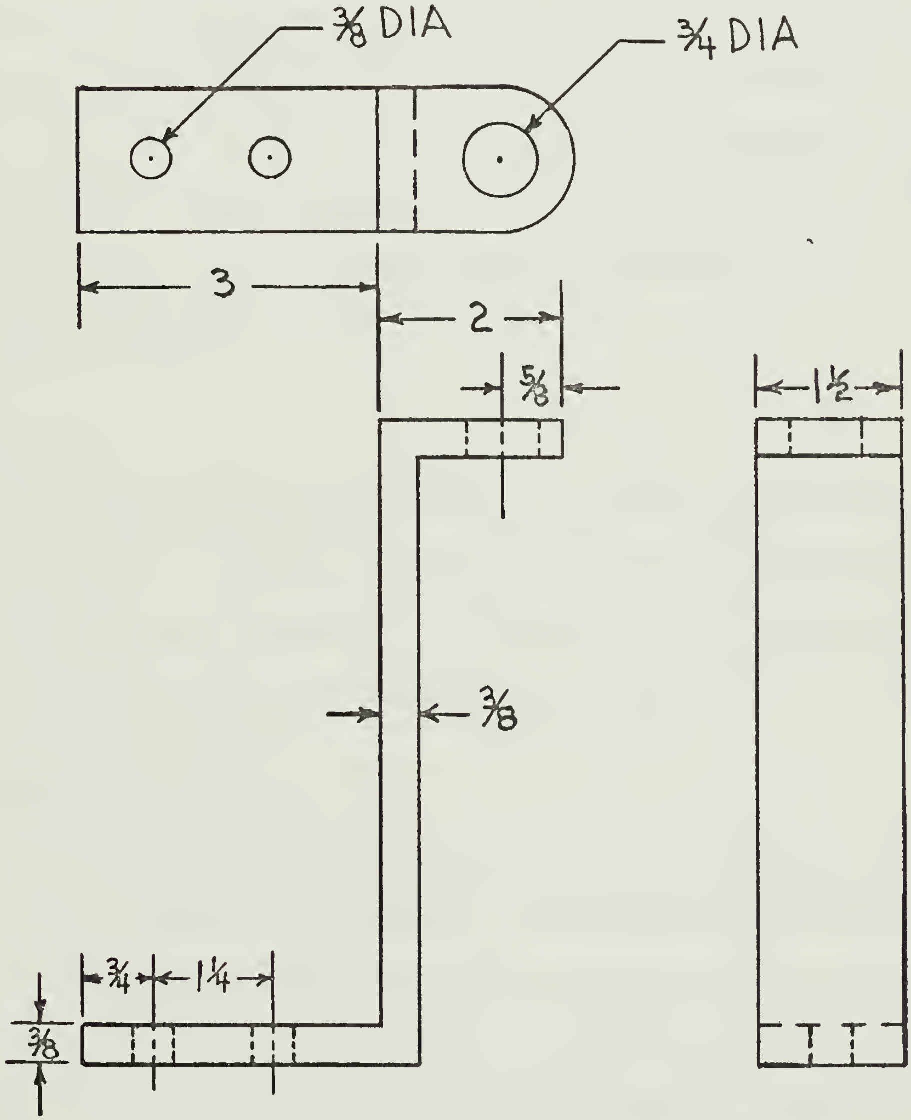


Figure 8.

Detail of the Upper Platform

Figure 9.

Detail of the Displacement Transducer Support Bracket



lower platform and provides the support for the displacement transducer. The two enlarged bolt holes in the bracket allow for lateral movement so that proper alignment of the displacement transducer end probe can be achieved. The displacement transducer is secured to the bracket by means of a lock-nut. The support bracket is constructed from welded strips of aluminum.

JACTUATOR SHAFT UPPER PLATEN

The jactuator shaft upper platen in Figure 10 is made of lightweight aluminum finely machined so as to provide a mirror-like finish on its lower surface. This smooth surface bears on the top of the sediment sample and is intended to give equal transmission of load throughout the sample. The upper platen screws on the jactuator shaft and serves to secure the mechanical extension arm to it.

JACTUATOR SPACER

The jactuator spacer shown in Figure 11 is made of aluminum, machined such that it conforms to the base of the jactuator, and sits between the jactuator and the upper platform. It allows for proper alignment between the motor output shaft and the jactuator input shaft.

SHAFT EXTENSION ARMS

The shaft extension arms of both the jactuator shaft and the weighted piston shaft are displayed in Figure 12. The purpose of these arms is to provide mechanical extensions which move up and down with their respective shafts so as to bear on the displacement transducer end probe. Hence, any shaft movement is exactly transmitted via the mechanical arms to the end probe. After proper calibration, the precise position of the upper platen

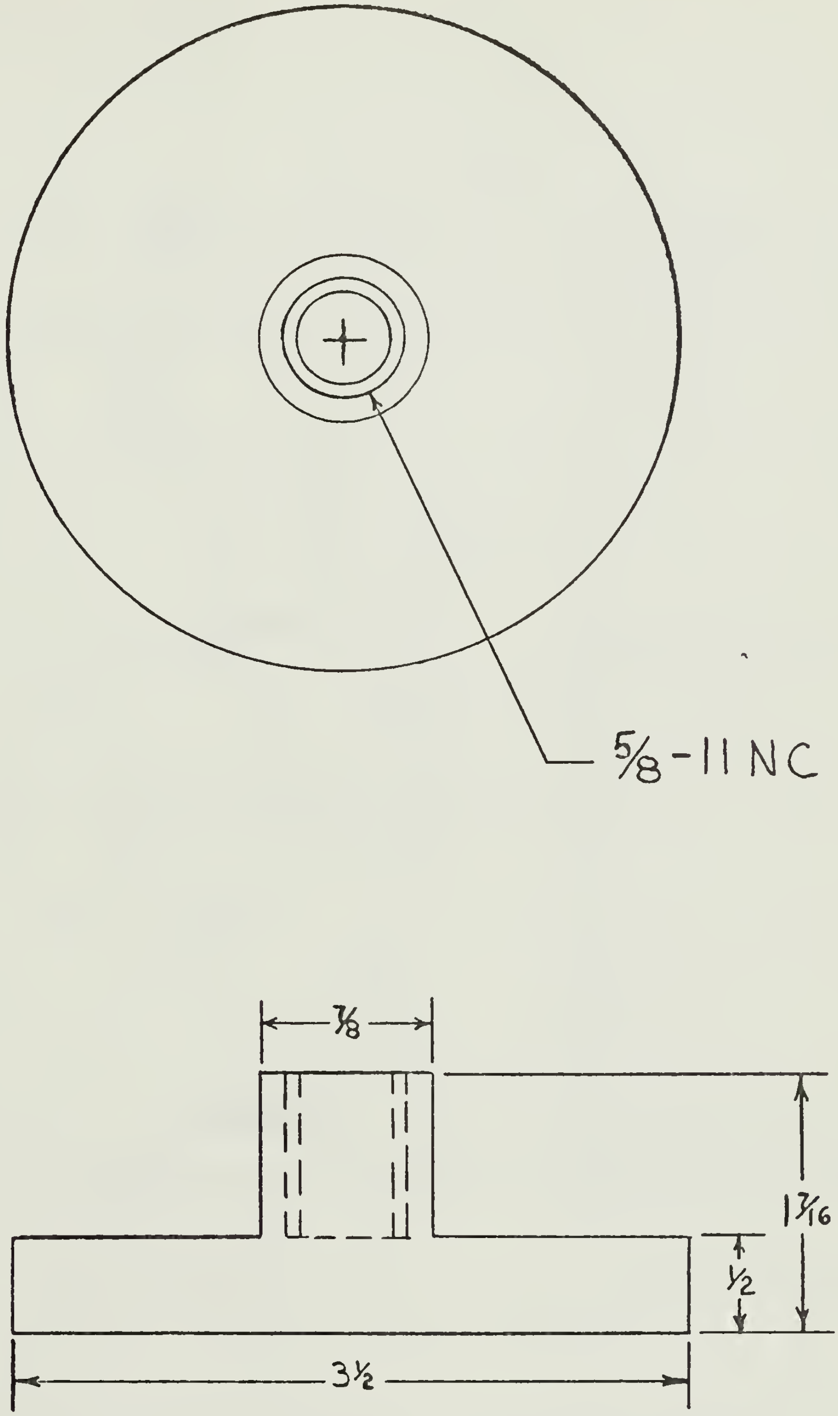


Figure 10. Detail of the Jactuator Shaft Upper Platen

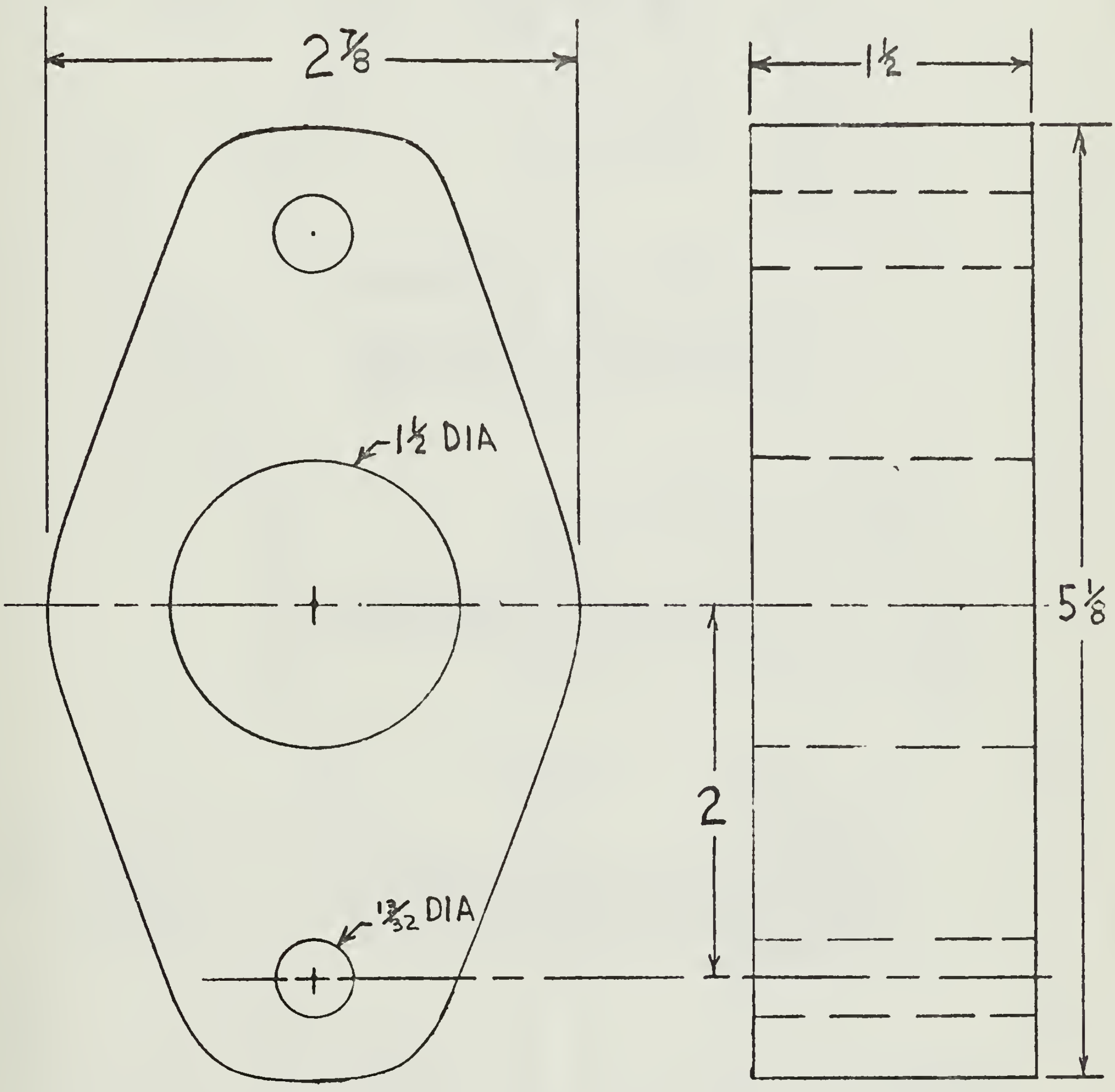


Figure 11. Detail of the Jactuator Spacer

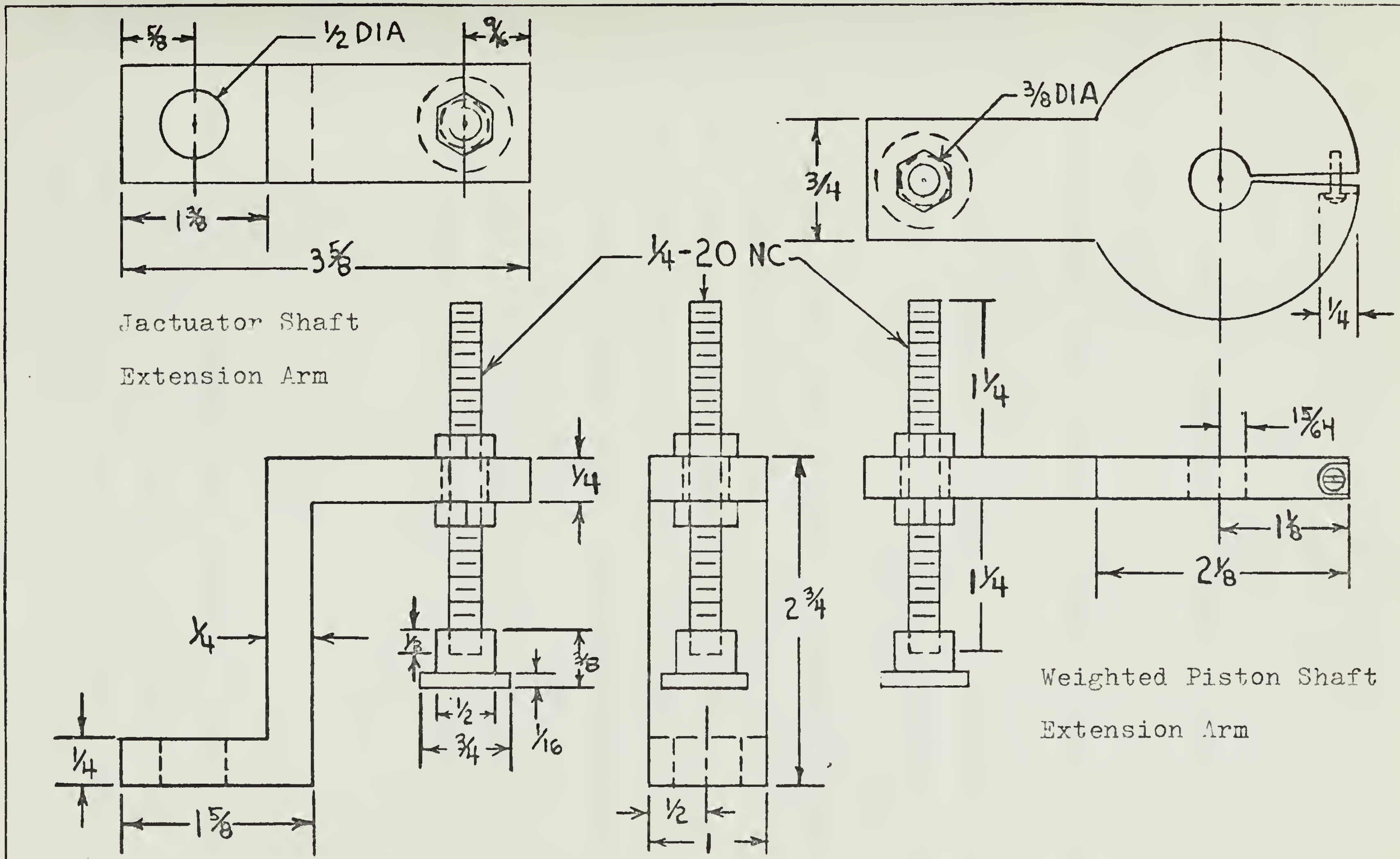


Figure 12. Detail of the Shaft Extension Arms

is continuously known. The extension arm for the jactuator shaft is secured to the shaft by means of the upper platen. The weighted piston shaft extension arm is fastened to the weighted piston shaft by a split-ring clamp tightened by a set screw. Both extension arms are provided with screw adjustments used to facilitate displacement transducer calibration.

WEIGHTED PISTON ASSEMBLY

The weighted piston shown in Figure 13 consists of three pieces: the weight holder, the weighted piston shaft and the weighted piston upper platen. These can be conveniently assembled on the unconfined compression testing machine when shifting to the stress-controlled mode of testing. Each piece was made as light in weight as consistent with strength in order to reduce the initial load increment placed on the sediment sample to a minimum. The weight holder was hollowed out both to reduce its weight and to help retain the small lead discs used for the increment loading. The weighted piston shaft screws into the weight holder after positioning through the ball bushing during assembly. The shaft extension arm and the weighted piston upper platen are normally left attached to the shaft. The upper platen screws on to the shaft and is constructed similarly to the jactuator upper platen. The entire weighted piston assembly weighs 1.8 pounds.

LEAD DISCS

Forty 1/8-pound and twenty 1/4-pound lead discs 1 5/8 inches in diameter provide the load increments for the stress-controlled mode of testing. Combinations of these discs allow selection of the proper load increments based on the expected value of sediment shear strength. Ideally the sample should fail somewhere between the application of the tenth and the fifteenth equal load increment.

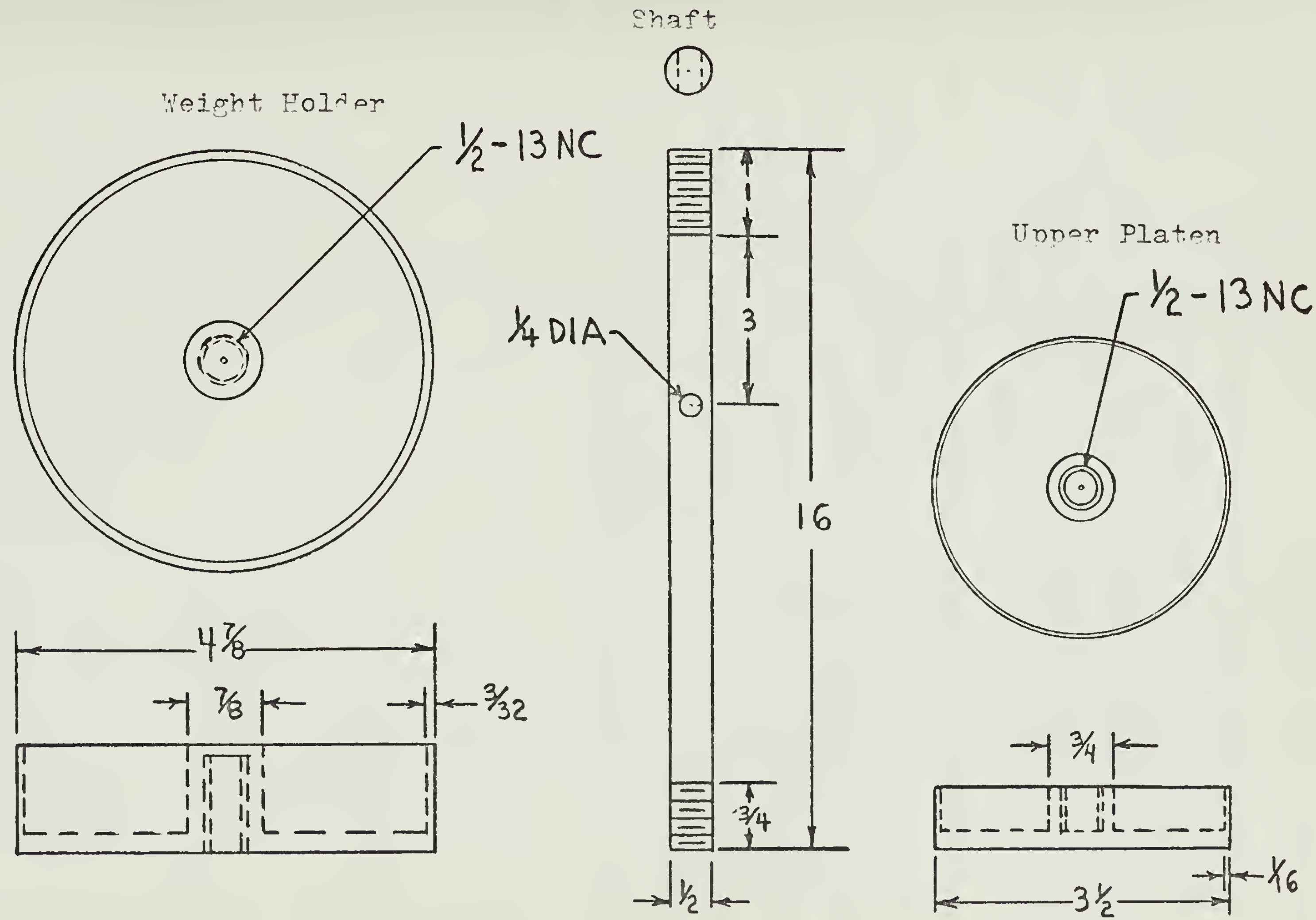


Figure 13. Detail of the Weighted Piston Assembly

BALL BUSHING AND PILLOW BLOCK

The ball bushing used on the unconfined compression testing machine in the stress-controlled mode is a Model A-81420-SS manufactured by the Thomson Industries, Inc., of Manhasset, New York. Made of stainless steel, the bushing precisely guides the 1/2-inch diameter weighted piston shaft by a unique arrangement of ball bearings providing almost friction-free linear motion. Binding and chatter of the shaft are eliminated by use of the bushing and a precision alignment is maintained. Since the bushing does not depend on an exposed oil film, lubrication is not necessary. The ball bushing is housed in a Model PB-8-A Pillow Block made by the same company. This pillow block, built specifically for the ball bushing, provides a convenient housing and permits adjustment of the shaft alignment to achieve a vertical position. The pillow block with its installed ball bushing is mounted to the upper platform of the machine by two mounting bolts.

IV. TEST PROCEDURES

GENERAL

Prior to testing a complete set of detailed test procedures were written covering sequentially each phase, and during the tests changes were made to these procedures to ensure their correctness and completeness. The test procedures contained in the following sections reflect these changes and are presented in a step-by-step manner for ease in use.

INITIAL ADJUSTMENT OF THE TRANSDUCER AMPLIFIER-INDICATORS

1. The force transducer and the displacement transducer are connected to the Type 70 Input Modules on their respective amplifier-indicators using Type 22S shielded cables with amphenol connectors.

2. The amplifier-indicator power cables are connected to a 115 volt, 60 Hertz, grounded power source of adequate capacity.

3. A zero check of each amplifier-indicator is made as follows:

   a. The Range Selector Switch is turned to the STANDBY Position which shorts the amplifier input.

   b. The SENSITIVITY Control Knob is turned fully clockwise. All controls are ten-turn types with friction drive, making it difficult to determine the end of travel. To position in the midpoint, the knob is turned at least ten turns in one direction and then turned five turns in the opposite direction.

   c. The METER POLARITY Switch is switched to the NORMAL Position.

   d. The POWER Switch is switched to the ON Position and ten minutes are allowed for stabilization. The meter indication should be within one quarter division from zero. If it is greater than this amount, adjustment is made for exactly zero indication using the mechanical adjustment on the face of the meter.

4. The TRANSDUCER CONDITIONING SELECTOR Switch is turned to Position B on the force transducer amplifier-indicator. On the displacement transducer amplifier-indicator Position D is selected.

5. Null adjustment for each transducer is accomplished as follows:

a. The SENSITIVITY, ZERO, and NULL Control Knobs are positioned to the approximate midpoint of their travel. The mechanical input to each transducer is ascertained to be in the condition desired as zero reference, i.e., no load on the weighing platform and the displacement transducer at its mid-point of travel.

b. The RANGE SELECTOR Switch is turned to the NULL Position converting the amplifier-indicator to a simple, nonphase sensitive AC voltmeter.

c. The transducer mechanical zero adjustment (or position) is adjusted to achieve minimum meter reading. This adjustment on the force transducer requires removing both the weighing platform and the locking screw from the transducer shaft. The adjustment set screw, found underneath the locking screw, is adjusted to give a minimum reading.

d. The NULL Control Knob is adjusted to get a minimum reading less than that obtained in the previous step.

e. Alternately the mechanical zero adjustment and the NULL Control Knob are adjusted until no further reduction in meter reading is obtained. During the adjustment, the SENSITIVITY Control Knob is turned fully clockwise to get maximum resolution. Minimum null value is usually less than two divisions. If the mechanical zero adjustment is too coarse to permit such adjustment, the final stages of the process are carried out using the ZERO Control Knob in lieu of the mechanical zero adjustment. The locking screw and weighing platform are then replaced.

6. Using shielded cables, the recorder output for the force transducer amplifier-indicator is connected to the Y-axis of the X-Y Recorder. Similarly, the recorder output from the displacement transducer amplifier-indicator is connected to the X-axis of the X-Y Recorder.

7. The X-Y Recorder is connected to a 115 volt, 60 Hertz, grounded power supply.

8. The amplifier-indicators are now considered to be in adjustment and ready for their calibration procedure.

CALIBRATION OF THE TRANSDUCER AMPLIFIER-INDICATORS

1. The RANGE SELECTOR Switches on both transducer amplifier-indicators are placed in the STANDBY Position. The POWER Switches are switched to the ON Position and both amplifier-indicators are allowed five minutes to warm up.

2. The METER POLARITY Switches on both amplifier-indicators are checked in their NORMAL Position.

3. The RANGE SELECTOR Switch for the amplifier-indicator connected to the force transducer is turned to Position 1. Similarly, the RANGE SELECTOR Switch on the amplifier-indicator connected to the displacement transducer is switched to Position 100. In this position full scale indication on the force transducer amplifier-indicator meter is ten pounds while full scale on the displacement transducer amplifier-indicator meter is 0.5 inches.

4. A piece of graph paper is placed in the X-Y Recorder and the recorder is placed in its operational mode with its pen up.

5. With the weighing platform installed and no force applied to it, the force transducer meter and the recorder Y-axis are checked in

the zero position. If they are not on zero, the ZERO Control Knob is adjusted to give proper meter zero and then the recorder zero adjustment is made with its Zero Adjustment Knob.

6. To calibrate the force transducer amplifier-indicator a known weight of exactly five pounds is placed on the weighing platform and both the meter and recorder indications are read. If the meter does not indicate five pounds, the SENSITIVITY Control Knob is adjusted to give a precise indication of five pounds. The Range Selector Switch is shifted to the CAL Position and the CAL REFERENCE Control Knob is adjusted to give exactly full scale indication. The Range Selector Switch is then shifted back to Position 1 and the recorder Y-axis is checked to insure it is indicating five pounds. If it is not indicating properly, a recorder adjustment is made. This requires simultaneous adjustment of the 5-55 millivolt Recorder Output Adjustment Knob found on the back of the amplifier-indicator and the recorder Y-axis zero adjustment to achieve a proper linear signal into the recorder. If linear calibration on the recorder still is not obtained, the recorder Y-axis variable adjustment is used to make the final calibration. The force transducer amplifier-indicator is now considered calibrated.

7. The upper platen of the unconfined compression testing machine is positioned to give a dial caliper indication of 4.5 inches between it and the weighing platform. If the machine is rigged in the strain control mode, the SPEED RANGE Switch on the motor controller is switched to the HIGH Position and the maximum speed setting on the SPEED CONTROL Potentiometer is used to facilitate positioning the platen. The displacement transducer amplifier-indicator meter and the recorder X-axis indications are checked in the zero position. If not on zero, the screw adjustment on the shaft extension arm which moves the displacement transducer end probe is adjusted

to give a meter indication of zero. The recorder X-axis is then adjusted to zero.

8. Using the dial caliper for indication, the upper platen is placed precisely five inches above the weighing platform. The amplifier-indicator meter is now checked. If not on plus 0.5 inches (full scale indication), the SENSITIVITY Control Knob is adjusted to give a reading of precisely 0.5 inches. This plus 0.5 inches corresponds to a sample height of five inches. The Range Selector Switch is shifted to the CAL Position and the CAL REFERENCE Control Knob is adjusted to give exactly full scale indication. The Range Selector Switch is shifted to Position 100 and the recorder X-axis is checked to insure it is indicating its zero position corresponding to a sample height of five inches. If the recorder does not indicate this displacement, a recorder adjustment is made. This requires an adjustment similar to that made in Step 6, only using the Recorder Output Adjustment Knob for the displacement transducer amplifier-indicator and the X-axis zero adjustment. The displacement transducer amplifier-indicator is now considered calibrated.

MACHINE CONVERSION TO THE STRAIN-CONTROLLED MODE

1. The variable speed motor cable is connected to the motor speed controller and the controller is plugged into a 115 volt, 60 Hertz, grounded power supply.

2. The jactuator spacer is placed in position on the upper platform. The jactuator shaft without its upper platen installed is placed through the spacer and the upper platform until the jactuator base rests on the spacer.

3. The jactuator input shaft is then connected to the rigid coupling normally left on the motor output shaft. The jactuator input shaft keyway is aligned to receive the rigid coupling set screw. The set screw is tightened. It is found that this is a critical step because any relative motions between the shafts cause a variation in load.

4. Both mounting bolts are installed through the jactuator base, spacer and upper platform. Their nuts are tightened,securing the jactuator to the upper platform.

5. The jactuator shaft extension arm and the upper platen are installed on the jactuator shaft. The upper platen is tightened with the extension arm screw adjustment aligned on the displacement transducer end probe.

6. The calibration procedure for the transducer amplifier-indicators is conducted to check on the system calibration. Once the upper platen is placed at a height of 4.5 inches above the weighing platform and the extension arm screw adjustment is adjusted to give zero indication on the displacement transducer amplifier-indicator meter, the system is generally found to be in calibration.

7. The upper platen is positioned to a height of approximately 5.1 inches above the weighing platform using the recorder indication.

8. The SPEED RANGE Switch on the motor speed controller is switched to the LO Position. The SPEED CONTROL Potentiometer is set at .41 which corresponded to a rate of strain of 0.1 inches per minute or two percent per minute for a five-inch sample. The machine is now ready to receive the sample.

MACHINE CONVERSION TO THE STRESS-CONTROLLED MODE

1. The unconfined compression testing machine is unrigged from the strain-controlled mode by reversing the order of its assembly.

2. The ball bushing pillow block is tightly bolted to the upper platform using its two mounting bolts.

3. The weighted piston shaft, with its extension arm and upper platen already attached, is put in position up through the ball bushing. The weight holder is screwed tightly on the upper end of the shaft.

4. The weighted piston assembly is manually raised and positioned so that the extension arm screw adjustment is centered on the displacement transducer end probe.

5. A calibration check is made on the displacement transducer amplifier-indicator. Once the calibration check is made, a pin is placed through a hole in the weighted piston shaft and the assembly is lowered until the pin rests on the ball bushing. This positions the upper platen approximately 5.1 inches above the weighing platform. The machine is ready to receive the sample.

PREPARATION OF THE UNDISTURBED SAMPLE

1. The exterior surface of the core plastic liner is wiped clean and dry.

2. Starting at the top of the core, the plastic liner is marked with a waterproof marking pen at the desired cutting locations. A sequence of one three-inch section followed by two five-inch sections is repeated throughout the length of the core.

3. The cutting guide collar (Smith and Nunes, 1964), shown in Figure 14, is placed at the first cutting mark. The guide clamp is tightened.

4. Using the Weller D-550 soldering gun and the modified cutting tip (Smith and Nunes, 1964) also shown in Figure 14, the plastic liner is circumferentially cut at the first position.

Figure 14. The Coping Saw, Soldering Gun and Guide Collar

5. A coping saw equipped with a piano wire for a blade is used to cut carefully through the core.

6. Steps 3, 4, and 5 are repeated for the next cutting position.

7. The three-inch section is carefully removed, the bottom of its plastic liner capped, and the sediment shear strength is measured with a vane shear apparatus (Heck, in press) without removing the sediment from the plastic liner.

8. Step 6 is repeated for the following five-inch section.

9. The five-inch section is removed and immediately placed on a spatula in a vertical position. This prevents the sediment from coming out of the core plastic liner.

10. The plastic liner is placed in a clamping device and held there while a hand ejection piston is used to carefully extrude the sample with a minimum of disturbance. The sample is maintained on the spatula during this step and very little disturbance occurrs.

11. Using the spatula, the sample is placed in the center of the force transducer weighing platform and the spatula is removed.

12. The X-Y Recorder Operating Switch is placed in the PEN Position. The recorder graph indicates the sample weight and is ready for testing.

TESTING IN THE STRAIN-CONTROLLED MODE

1. The Motor Controller Operating Switch is turned to the FWD Position. This causes the upper platen to be driven downward at an axial rate of strain of two percent per minute. Care is taken to insure that good contact is made between the upper platen and the sample.

2. The X-Y Recorder graph is checked to see that a good reading is being made.

3. When a distance of at least 20 percent of the initial sample height is traversed by the upper platen, the Motor Controller Operating Switch is turned to the BRAKE Position.

4. This is considered the end of the test and the X-Y Recorder Operating Switch is placed in its OPERATE Position which lifts the pen.

5. The Motor Controller Operating Switch is turned to the REVERSE Position, the SPEED RANGE Switch placed in the HI Position, and the SPEED CONTROL Potentiometer turned to its maximum setting. This raises the upper platen off the sample.

6. When the upper platen is about 5.1 inches above the weighing platform as indicated on the recorder, the Motor Controller Operating Switch is turned to the BRAKE Position.

7. Removal of the sample is accomplished by carefully unscrewing the weighing platform from the force transducer and carrying the platform with the sample on it to a desired location where the sample is removed.

8. The weighing platform and the upper platen are wiped clean and the platform reinstalled on the force transducer.

9. The X-Y Recorder Operating Switch is placed in its load position. This allows removal of the graph paper with its load versus sample height curve. A new piece of graph paper is installed. The recorder is placed in its operational mode with its pen up ready for the next test.

TESTING IN THE STRESS-CONTROLLED MODE

1. Based on the expected value of sediment shear strength, the weight increment of loading is chosen. Generally, 1/4-pound or 3/8-pound increments are used. These increments are made up of combinations of the 1/4-pound and 1/8-pound discs.

2. The timer is plugged into a 115 volt, 60 Hertz, grounded, power supply and turned on.

3. The pin is removed from the weighted piston shaft and the shaft slowly lowered until the upper platen rests evenly on the top of the sediment sample. This is considered the first load increment. The time at which contact is made with the sample is noted.

4. After the first load increment, the previously chosen increment of weight is placed on top of the weight holder at 30 second intervals.

5. Incremental loading is continued until the upper platen has traveled at least 20 percent of the initial sample height.

6. The X-Y Recorder Operating Switch is placed in its OPERATE Position which lifts the pen. It is then placed in its LOAD Position.

7. The lead discs are removed from the top of the weight holder. The weighted piston shaft is slowly raised until the upper platen is clear of the sample. The shaft is then pinned in its starting position.

8. Sample removal and the replacing of graph paper in the recorder are accomplished in a manner identically described in the testing procedure for the strain-controlled mode of operation.

V. TEST RESULTS

On April 23, 1970, a sediment sampling program was carried out from the USNS BARTLETT (T-AGOR-13). The vessel departed from the port of Oakland and proceeded southwesterly along the continental slope between San Francisco and Monterey. At the ten locations along the track shown in Figure 15, the ship was stopped and an Ewing gravity corer with 450 pounds of weight was used to obtain a core. The sediment samples varied in length from 39 to 71.5 inches. The depth of water at the core locations ranged from 340 to 1870 fathoms. In each case the core liner was removed from the core barrel, capped, sealed and placed vertically in a specially constructed storage drum filled with sea water. This storage drum was carefully removed from the ship upon return to port and placed in storage until the test program commenced on the 3rd of August. A summary of the coring data is presented in Table I. All cores were dark green colored clays, with the exception of Core 1W and Core 2W which both contained some sand.

Between August 3rd and August 5th the ten cores were analyzed as follows. The top three-inch section was removed from the core and tested on the NPS vane shear apparatus (Heck, in press) to determine a vane shear strength value. This three-inch section was then remolded to determine its sensitivity and a portion was used to obtain the water content. A summary of the values computed for the vane shear strength, sensitivity, and water content for each sample appear on Table II through Table XI. Two five-inch sections were then removed from the core and tested on the NPS unconfined compression testing machine. The first five-inch section was tested using the strain-controlled mode and the second five-inch

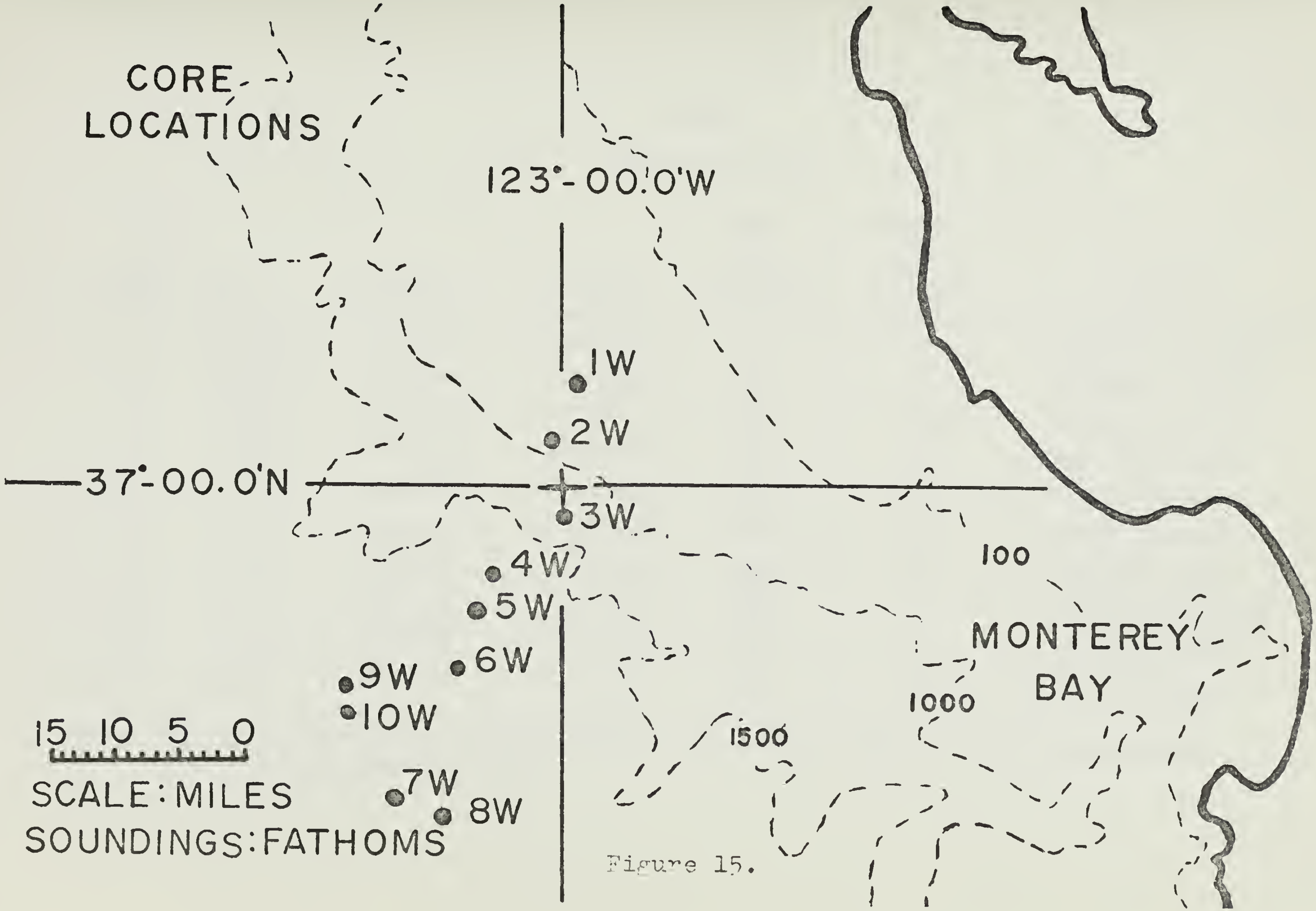

CORE
LOCATIONS
123°-00.0'W
37°-00.0'N
1W
2W
3W
4W
5W
6W
7W
8W
9W
10W
100
1000
1500
MONTEREY
BAY
15 10 5 0
SCALE: MILES
SOUNDINGS: FATHOMS

Figure 15.

TABLE I

CORE DATA SUMMARY

Core Number	Date	Latitude	Longitude	Depth of Water (Fathoms)	Length of Core (Inches)	Collected by
1 W	4/23/70	37-07.6N	122-58.6W	340	55	Westfahl & Hermann
2 W	4/23/70	37-03.6N	123-01.1W	750	71.5	Westfahl & Hermann
3 W	4/23/70	36-57.8N	123-00.0W	1390	71.5	Westfahl & Hermann
4 W	4/23/70	36-53.2N	123-07.2W	1676	60	Heck & Carlmark
5 W	4/23/70	36-50.0N	123-08.5W	1738	68	Heck & Carlmark
6 W	4/23/70	36-45.6N	123-10.5W	1755	47	Heck & Carlmark
7 W	4/23/70	36-35.7N	123-17.0W	1820	39	Westfahl & Heck
8 W	4/23/70	36-34.7N	123-12.3W	1822	39	Westfahl & Hermann
9 W	4/23/70	36-45.0N	123-21.3W	1870	47	Westfahl & Heck
10 W	4/23/70	36-43.2N	123-21.2W	1850	45.5	Heck & Carlmark

Note: All cores obtained on the USNS BARTLETT, Cruise Number 137006, using an Ewing Gravity Corer with 450 pounds of weight

TABLE II

CORE DATA SUMMARY SHEET

CORE NO 1 W

DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.178	1.8	44.8
3 - 8	.304	7.9	.364	.143	.225	.759	16.3			
8 - 13	.646	11.3	.776	.487	.632	.776	20.0			
13 - 16								.512	5.56	42.9
16 - 21	1.081	13.7	1.182	.931	1.043	1.182	20.0			
21 - 26	1.007	11.2	1.251	.855	1.114	1.285	20.0			
26 - 29								.464	3.12	39.3
29 - 34	.547	13.3	.581	.396	.441	.590	20.0			
34 - 39	.754	11.3	.873	.604	.738	.890	20.0			
39 - 42								.614	3.00	41.8
42 - 47	1.386	14.2	1.478	1.239	1.340	1.478	20.0			
47 - 52	1.256	13.4	1.362	1.112	1.229	1.362	20.0			
52 - 55								.631	1.93	39.8
55 - 60										
60 - 65										
65 - 68										

TABLE III

CORE DATA SUMMARY SHEET

CORE NO 2 W

DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.409	3.33	70.3
3 - 8	.768	18.0	.765	.628	.628	.768	18.0			
8 - 13	.698	14.5	.660	.580	.549	.691	17.5			
13 - 16								.563	7.17	87.2
16 - 21	.291	6.3	.315	.167	.209	.315	20.0			
21 - 26	.649	13.0	.644	.517	.522	.650	20.0			
26 - 29								.669	4.36	71.1
29 - 34	.889	15.6	.876	.750	.744	.889	15.5			
34 - 39	.820	13.0	.821	.682	.695	.840	15.0			
39 - 42								.955	5.71	45.9
42 - 47	.962	10.0	.950	.812	.823	.960	11.5			
47 - 52	.546	13.8	.575	.455	.491	.565	20.0			
52 - 55								.962	6.96	65.6
55 - 60	.944	13.3	.960	.812	.839	.960	17.5			
60 - 65	1.105	12.8	1.098	.975	.978	1.090	20.0			
65 - 68								.829	4.86	57.5

TABLE IV

CORE DATA SUMMARY SHEET

CORE NO 3 W

DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.819	5.00	107.0
3 - 8	.503	7.5	.517	.369	.401	.521	15.0			
8 - 13	.594	9.1	.633	.474	.528	.630	20.0			
13 - 16								.522	4.50	109.1
16 - 21	.548	11.7	.549	.431	.443	.551	13.9			
21 - 26	.340	9.0	.303	.215	.193	.340	12.5			
26 - 29								.580	5.67	104.6
29 - 34	.561	9.5	.573	.442	.468	.571	19.7			
34 - 39	.521	10.6	.559	.400	.451	.560	16.0			
39 - 42								.460	5.63	104
42 - 47	.442	10.4	.468	.324	.362	.468	20.0			
47 - 52	.621	13.1	.572	.493	.454	.640	20.0			
52 - 55								.478	5.83	78.6
55 - 60	.570	13.1	.566	.455	.460	.570	15.0			
60 - 65	.645	13.5	.644	.519	.528	.655	20.0			
65 - 68								.655	1.01	41.9

TABLE V

CORE DATA SUMMARY SHEET

CORE NO 4 W

DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.143	4.2	220.2
3 - 8	.267	12.7	.270	.164	.175	.271	18.0			
8 - 13	.316	12.9	.314	.205	.211	.316	12.5			
13 - 16								.413	4.48	173.4
16 - 21	.446	15.5	.443	.342	.345	.446	17.5			
21 - 26	.538	15.0	.564	.429	.461	.540	20.0			
26 - 29								.495	3.72	150.8
29 - 34	.648	12.4	.649	.532	.544	.650	14.2			
34 - 39	.503	10.7	.533	.389	.431	.520	20.0			
39 - 42								.512	5.17	240.4
42 - 47	.500	10.4	.525	.382	.419	.523	20.0			
47 - 52	.507	14.7	.507	.387	.395	.519	13.3			
52 - 55								.471	4.06	126.4
55 - 60										
60 - 65										
65 - 68										

TABLE VI

CORE DATA SUMMARY SHEET

CORE NO 5 W

DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.150	2.44	213.9
3 - 8	.257	13.0	.251	.149	.152	.257	13.1			
8 - 13	.338	13.0	.336	.221	.228	.345	20.0			
13 - 16								.280	4.56	191.8
16 - 21	.428	12.3	.426	.324	.331	.429	17.3			
21 - 26	.455	13.9	.486	.349	.387	.460	15.0			
26 - 29								.382	3.11	163.1
29 - 34	.713	14.9	.707	.598	.598	.713	16.8			
34 - 39	.625	16.8	.633	.519	.531	.640	16.0			
39 - 42								.791	5.40	145.0
42 - 47	.576	9.9	.578	.458	.473	.580	15.9			
47 - 52	.436	8.9	.440	.308	.327	.444	14.0			
52 - 55								.525	4.82	145.1
55 - 60	.468	10.2	.469	.350	.363	.472	13.0			
60 - 65	.691	12.8	.707	.570	.596	.711	16.3			
65 - 68								.358	2.5	117.3

TABLE VII

CORE DATA SUMMARY SHEET

CORE NO 6 W

DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.106	3.88	254.1
3 - 8	.229	10.0	.231	.123	.137	.238	13.2			
8 - 13	.275	13.2	.281	.168	.183	.282	16.2			
13 - 16								.246	3.79	179.8
16 - 21	.284	9.5	.289	.196	.211	.289	20.0			
21 - 26	.506	14.8	.517	.401	.419	.514	15.7			
26 - 29								.860	2.42	172.8
29 - 34	.753	12.7	.749	.640	.646	.752	13.6			
34 - 39	.644	14.3	.676	.536	.574	.680	20.0			
39 - 42								.699	5.13	151.3
42 - 47	.525	15.3	.533	.413	.427	.532	20.0			
47 - 52										
52 - 55										
55 - 60										
60 - 65										
65 - 68										

TABLE VIII

CORE DATA SUMMARY SHEET

CORE NO 7 W

DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.184	3.60	235.0
3 - 8	.369	12.7	.369	.260	.270	.371	15.6			
8 - 13	.410	9.9	.430	.296	.328	.425	18.8			
13 - 16								.716	5.00	158.6
16 - 21	.577	12.5	.563	.467	.462	.576	12.5			
21 - 26	.581	9.8	.607	.462	.501	.615	20.0			
26 - 29								.686	6.28	137.2
29 - 34	.490	13.0	.491	.374	.384	.492	18.0			
34 - 39	.510	14.1	.534	.390	.422	.540	20.0			
39 - 42										
42 - 47										
47 - 52										
52 - 55										
55 - 60										
60 - 65										
65 - 68										

TABLE IX

CORE DATA SUMMARY SHEET

CORE NO 8 W

DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.249	4.56	221.5
3 - 8	.277	8.7	.291	.167	.195	.291	20.0			
8 - 13	.339	11.8	.346	.235	.252	.345	18.7			
13 - 16								.563	4.34	156.8
16 - 21	.532	14.7	.532	.435	.441	.532	15.0			
21 - 26	.617	13.4	.640	.506	.537	.640	20.0			
26 - 29								.546	4.71	116.5
29 - 34	.352	12.5	.354	.237	.248	.355	15.6			
34 - 39	.424	8.2	.479	.299	.370	.480	20.0			
39 - 42										
42 - 47										
47 - 52										
52 - 55										
55 - 60										
60 - 65										
65 - 68										

TABLE X

CORE DATA SUMMARY SHEET

CORE NO 9 W

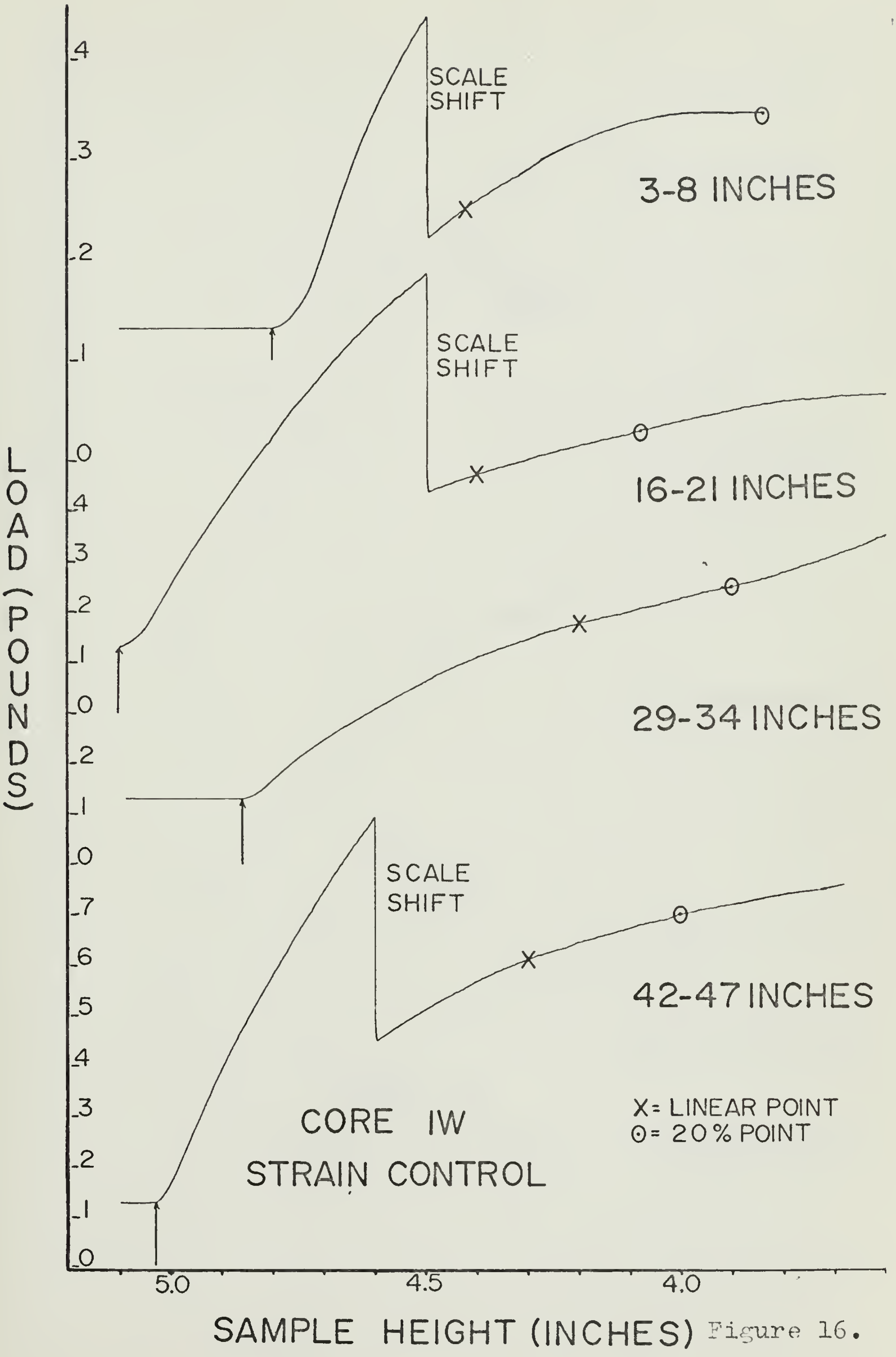
DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.409	5.00	197.8
3 - 8	.341	15.2	.343	.233	.241	.343	18.5			
8 - 13	.431	11.5	.449	.318	.346	.449	14.4			
13 - 16								.648	3.96	144.2
16 - 21	.488	14.0	.475	.375	.369	.488	14.2			
21 - 26	.572	12.8	.598	.458	.494	.600	20.0			
26 - 29								.682	6.90	132.7
29 - 34	.563	13.8	.570	.449	.464	.570	20.0			
34 - 39	.458	11.9	.464	.334	.352	.475	18.1			
39 - 42								.368	5.14	75.1
42 - 47	.319	9.7	.338	.195	.228	.338	20.0			
47 - 52										
52 - 55										
55 - 60										
60 - 65										
65 - 68										

TABLE XI CORE DATA SUMMARY SHEET CORE NO 10 W

DEPTH (INCHES)	LINEAR STRENGTH WITH SAMPLE WEIGHT (psi)	STRAIN AT LINEAR POINT (%)	STRENGTH AT 20% STRAIN WITH SAMPLE WEIGHT (psi)	LINEAR STRENGTH WITHOUT SAMPLE WEIGHT (psi)	STRENGTH AT 20% WITHOUT SAMPLE WEIGHT (psi)	MAXIMUM STRENGTH OF FAIRED STRESS-STRAIN (psi)	STRAIN AT MAXIMUM STRESS (%)	VANE SHEAR STRENGTH (psi)	SENSITIVITY	WATER CONTENT (%)
0 - 3								.201	4.21	243.9
3 - 8	.264	9.1	.283	.154	.186	.283	20.0			
8 - 13	.454	16.0	.454	.353	.357	.455	18.7			
13 - 16								.587	5.06	159.5
16 - 21	.551	9.2	.533	.435	.431	.544	11.5			
21 - 26	.629	10.0	.633	.512	.529	.640	12.7			
26 - 29								.641	4.00	138.9
29 - 34	.460	15.0	.458	.351	.356	.460	15.0			
34 - 39	.579	12.6	.586	.464	.480	.604	18.0			
39 - 42								.621	5.06	111.2
42 - 47										
47 - 52										
52 - 55										
55 - 60										
60 - 65										
65 - 68										

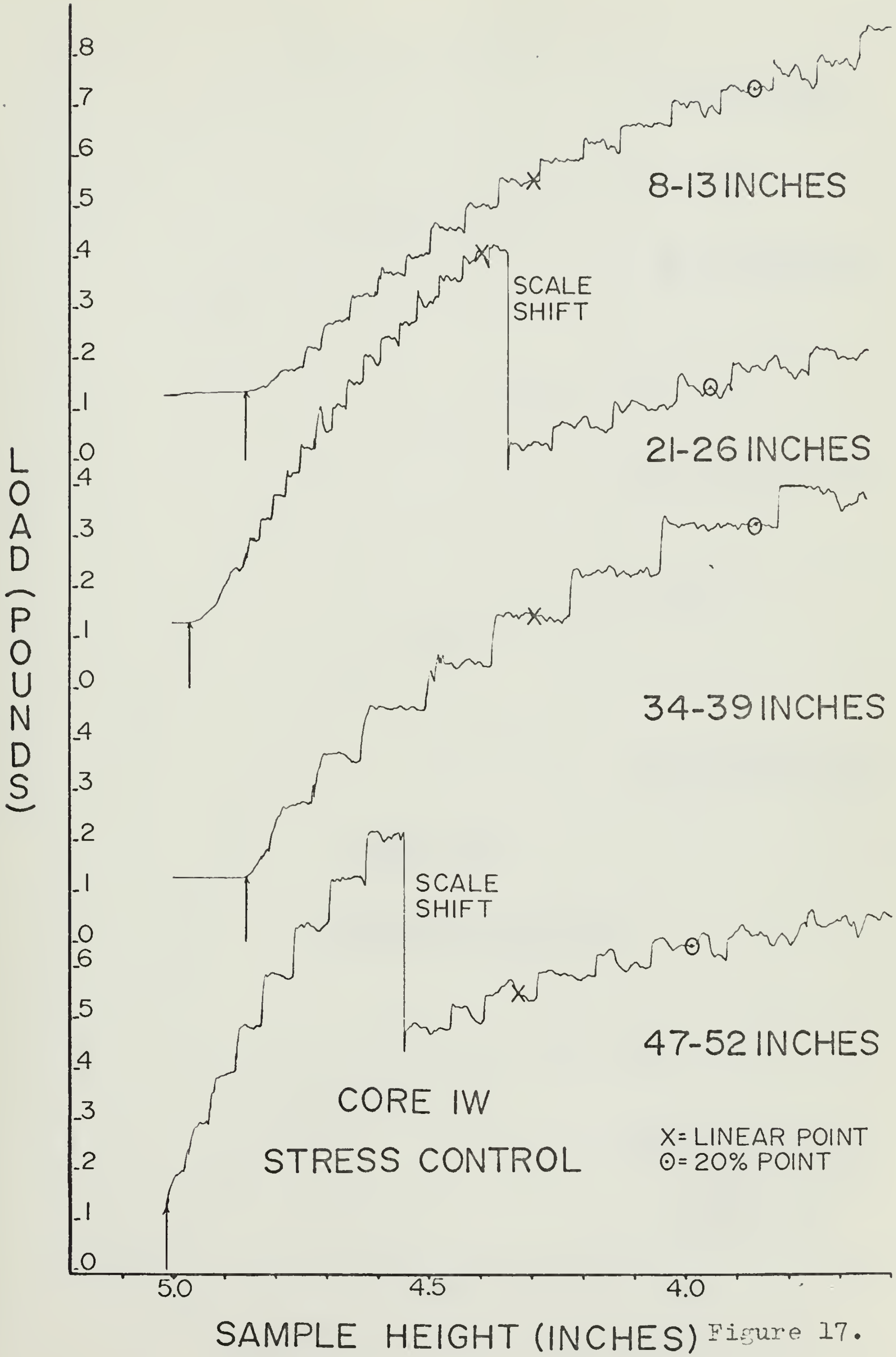
section the stress-controlled mode. The detailed test procedures described in the previous section were followed. In each case a recording of load versus sample height was made. The load values appearing on the record include the weight of the sample. Arrows were inserted on the curves shown in Figure 16 through Figure 35 to indicate sample height and sample weight. This sequence of testing was repeated throughout the length of each core. In conducting the strain-controlled tests on Core 1W, the rate of strain exceeded the recommended maximum value and hence the data for this particular test sample is considered questionable.

Figure 16 through Figure 35 depict the original load - sample height curves produced. Each figure combines those sections for one core which were tested in a similar mode of machine operation. It is believed significant that in all tests a point on each load - sample height plot is reached where the curve increases in a linear manner. The point at which such a linear increase begins is termed the linear point and its position is marked on each curve. Every observed sample physically sheared at approximately this location on the curve. Evidently the sample shears when the rate of change of load with respect to sample displacement becomes constant. This is considered important for a number of reasons. It would eliminate the necessity for continuing the test once linearity of the load - sample height curve is established and, if a large number of tests were being conducted, the time spent testing each sample would be reduced. Also, only one set of calculations would have to be made to compute the shear strength value. The value of load and displacement of the sample at the linear point would be used for these calculations. The sediment shear strength was computed using the value of load and sample displacement at the linear point and this is considered the linear strength value.



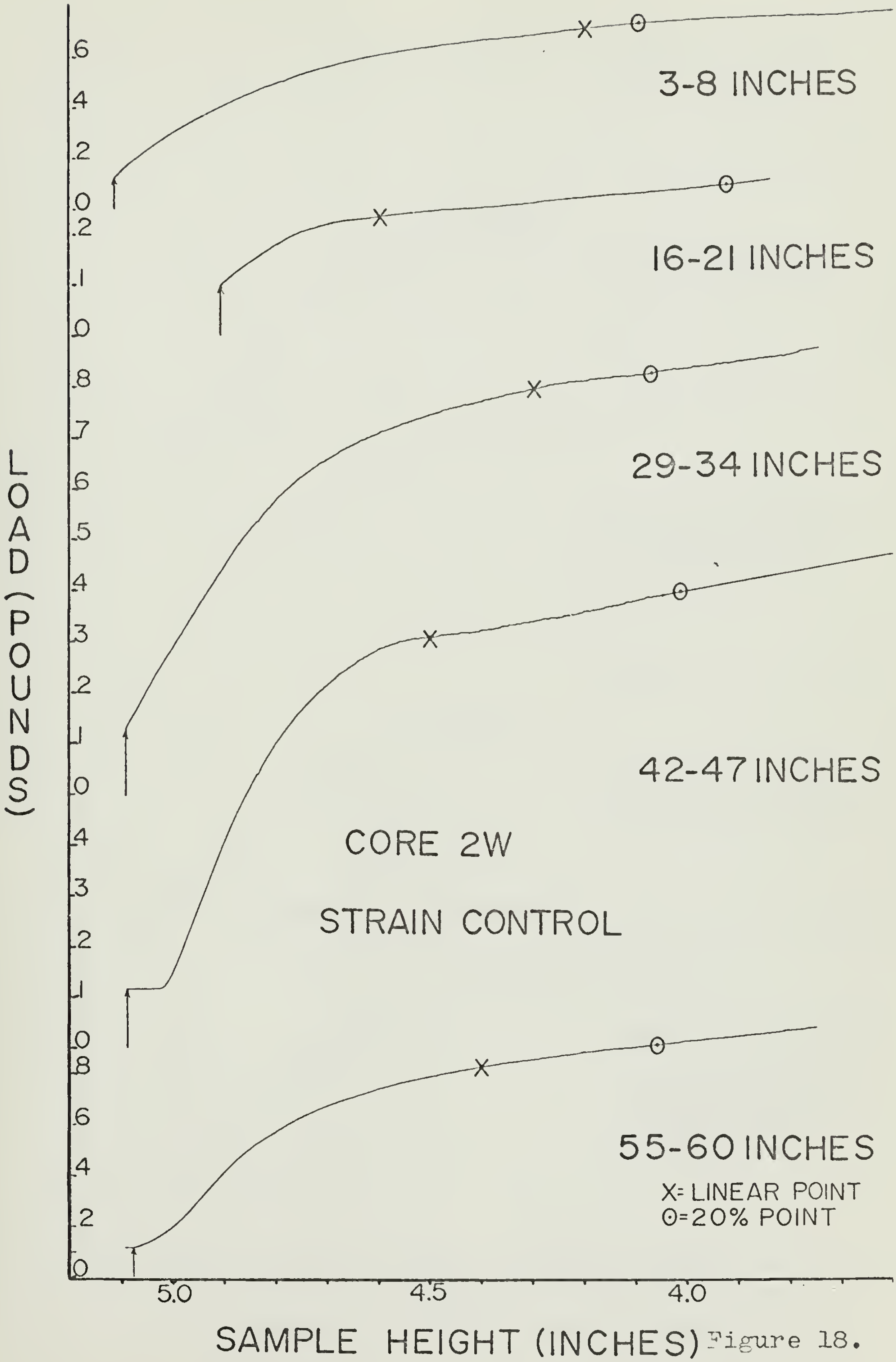
SCALE SHIFT
3-8 INCHES
SCALE SHIFT
16-21 INCHES
29-34 INCHES
SCALE SHIFT
42-47 INCHES
X= LINEAR POINT
⊙= 20% POINT
CORE IW
STRAIN CONTROL
LOAD (POUNDS)
SAMPLE HEIGHT (INCHES)
5.0
4.5
4.0

Figure 16.



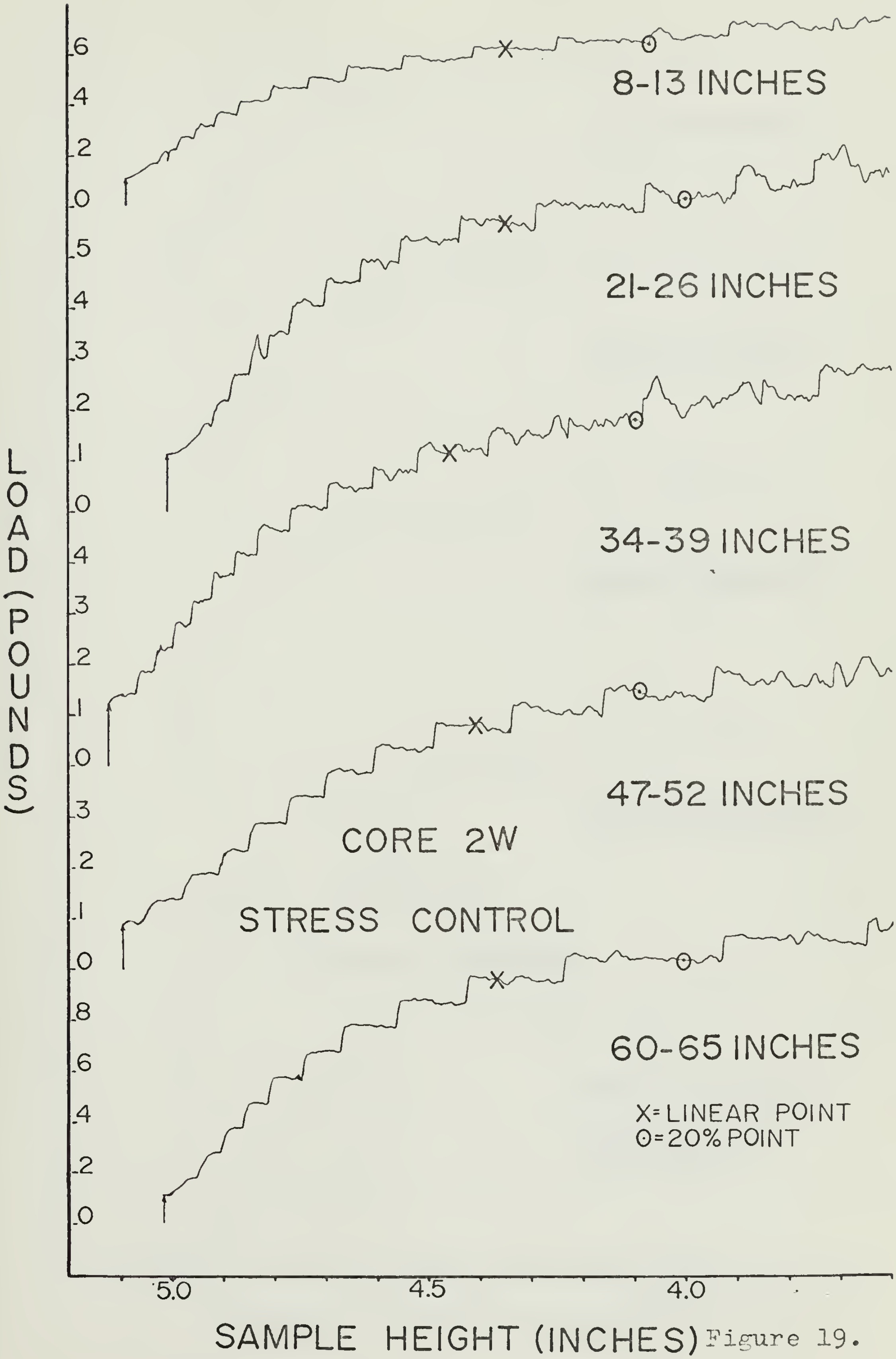
LOAD (POUNDS)
.8
.7
.6
.5
.4
.3
.2
.1
.0
.4
.3
.2
.1
.0
.4
.3
.2
.1
.0
.6
.5
.4
.3
.2
.1
.0
8-13 INCHES
SCALE SHIFT
21-26 INCHES
34-39 INCHES
SCALE SHIFT
47-52 INCHES
CORE IW
STRESS CONTROL
X= LINEAR POINT
⊙= 20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 17.



LOAD (POUNDS)
.6
.4
.2
.0
.2
.1
.0
.8
.7
.6
.5
.4
.3
.2
.1
.0
.4
.3
.2
.1
.0
.8
.6
.4
.2
0
3-8 INCHES
16-21 INCHES
29-34 INCHES
42-47 INCHES
CORE 2W
STRAIN CONTROL
55-60 INCHES
X= LINEAR POINT
⊙=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 18.



.6
.4
.2
.0
.5
.4
.3
.2
.1
.0
.4
.3
.2
.1
.0
.3
.2
.1
.0
.8
.6
.4
.2
.0
LOAD (POUNDS)
8-13 INCHES
21-26 INCHES
34-39 INCHES
47-52 INCHES
CORE 2W
STRESS CONTROL
60-65 INCHES
X=LINEAR POINT
⊙=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 19.

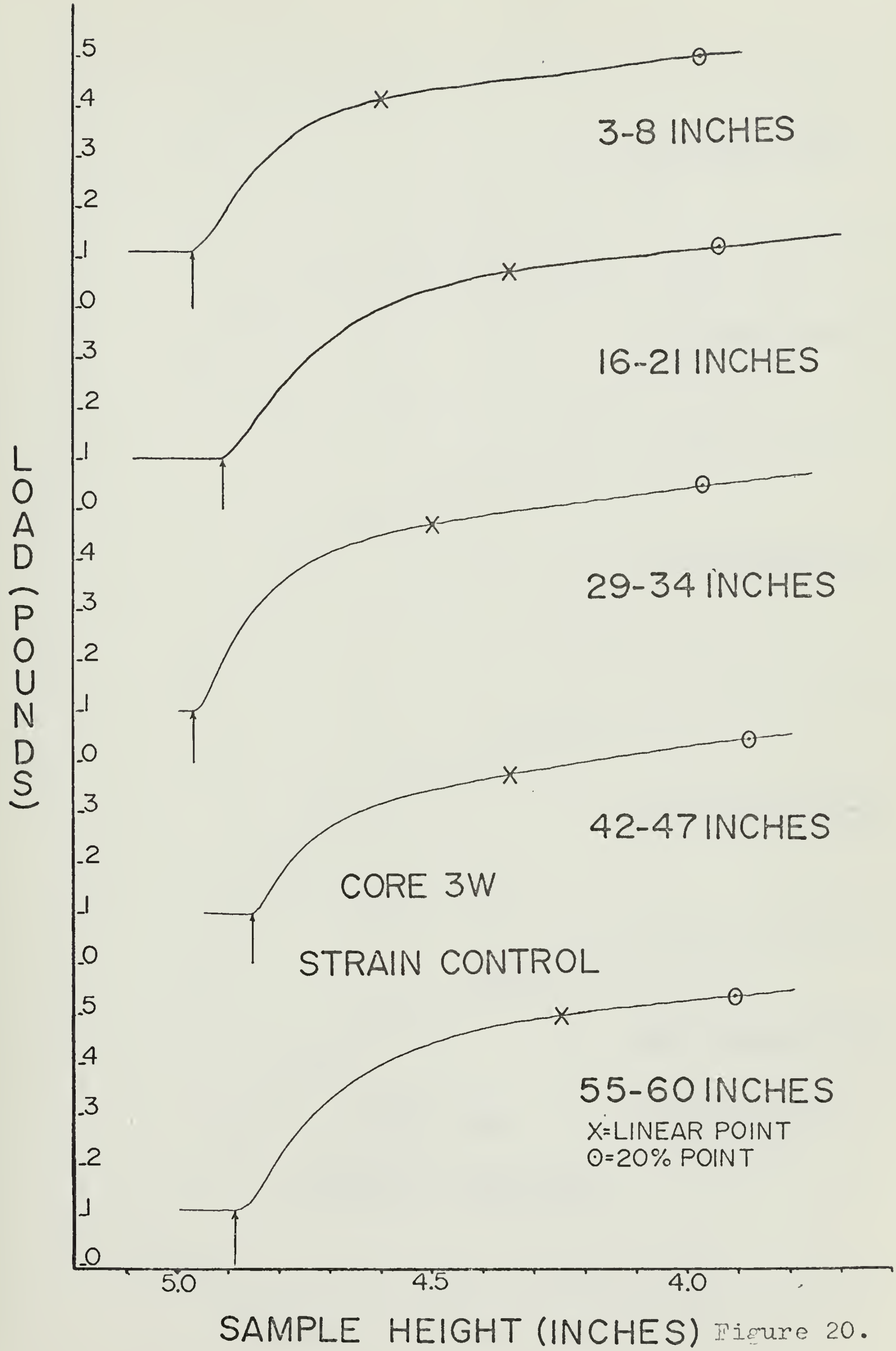
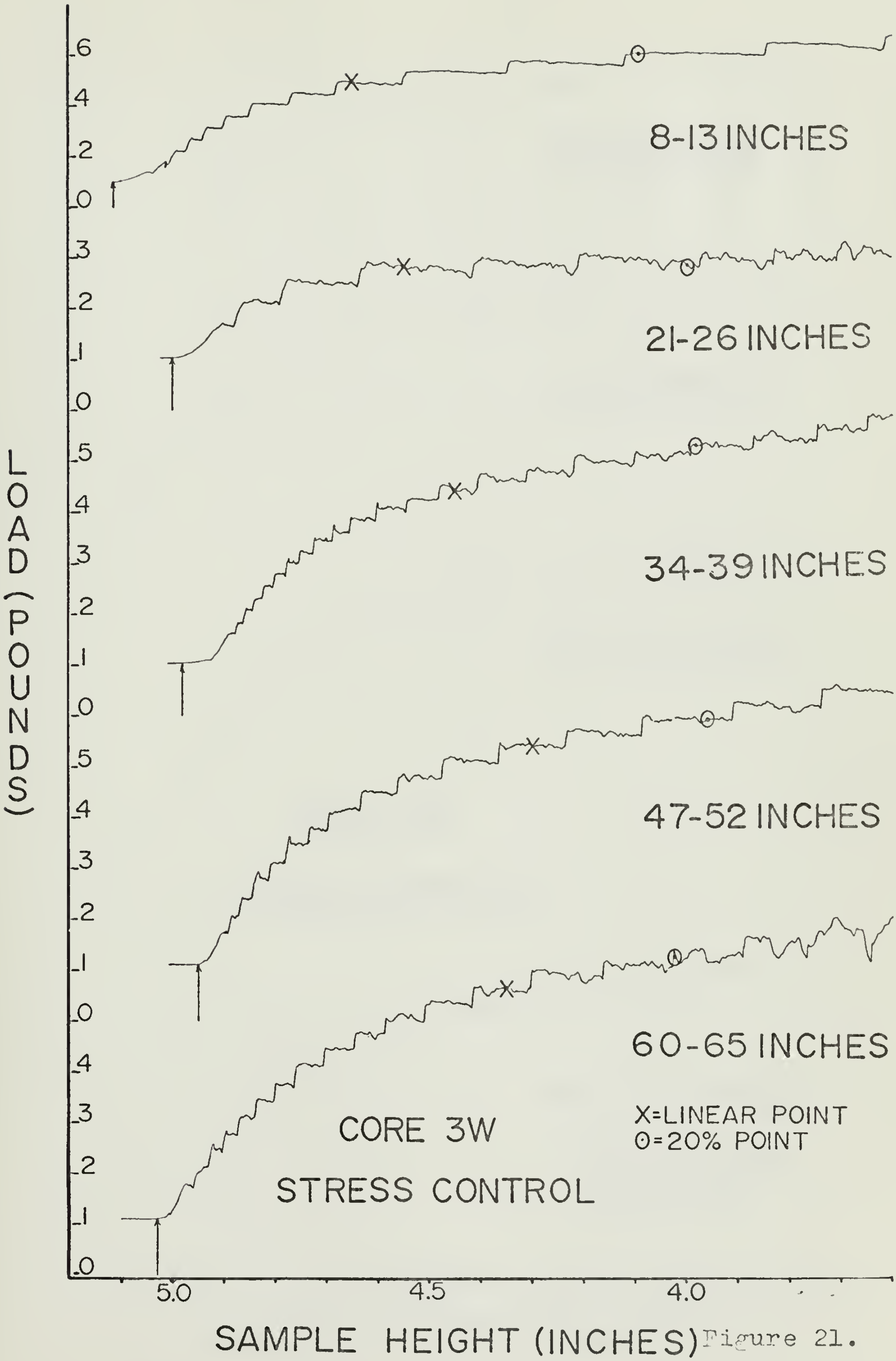

.5
.4
.3
.2
.1
.0
.3
.2
.1
.0
.4
.3
.2
.1
.0
.3
.2
.1
.0
.5
.4
.3
.2
.1
.0
LOAD (POUNDS)
3-8 INCHES
16-21 INCHES
29-34 INCHES
42-47 INCHES
CORE 3W
STRAIN CONTROL
55-60 INCHES
X=LINEAR POINT
O=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 20.



8-13 INCHES
21-26 INCHES
34-39 INCHES
47-52 INCHES
60-65 INCHES
X=LINEAR POINT
Θ=20% POINT
CORE 3W
STRESS CONTROL
LOAD (POUNDS)
.6
.4
.2
.0
.3
.2
.1
.0
.5
.4
.3
.2
.1
.0
.5
.4
.3
.2
.1
.0
.4
.3
.2
.1
.0
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 21.

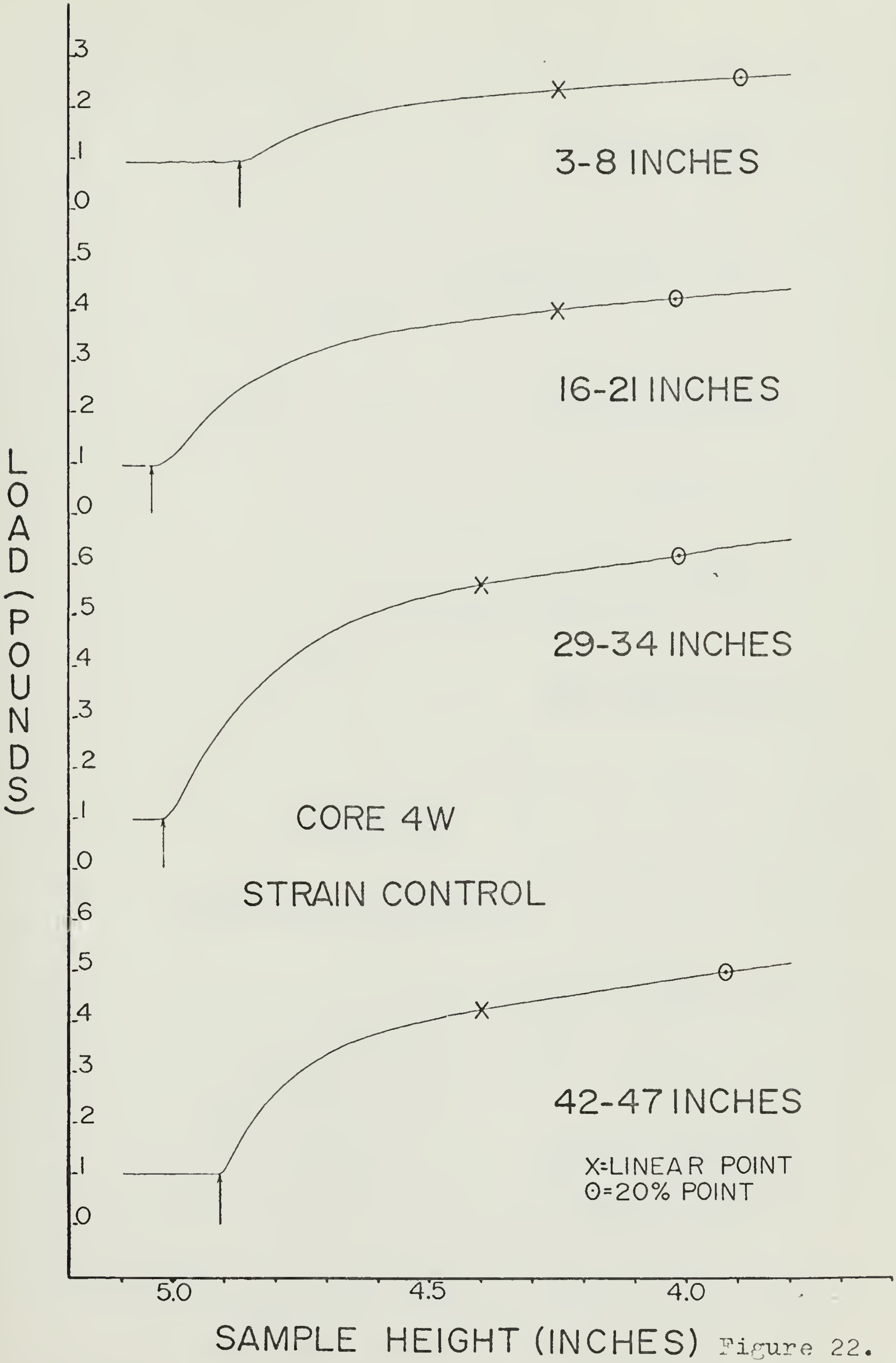
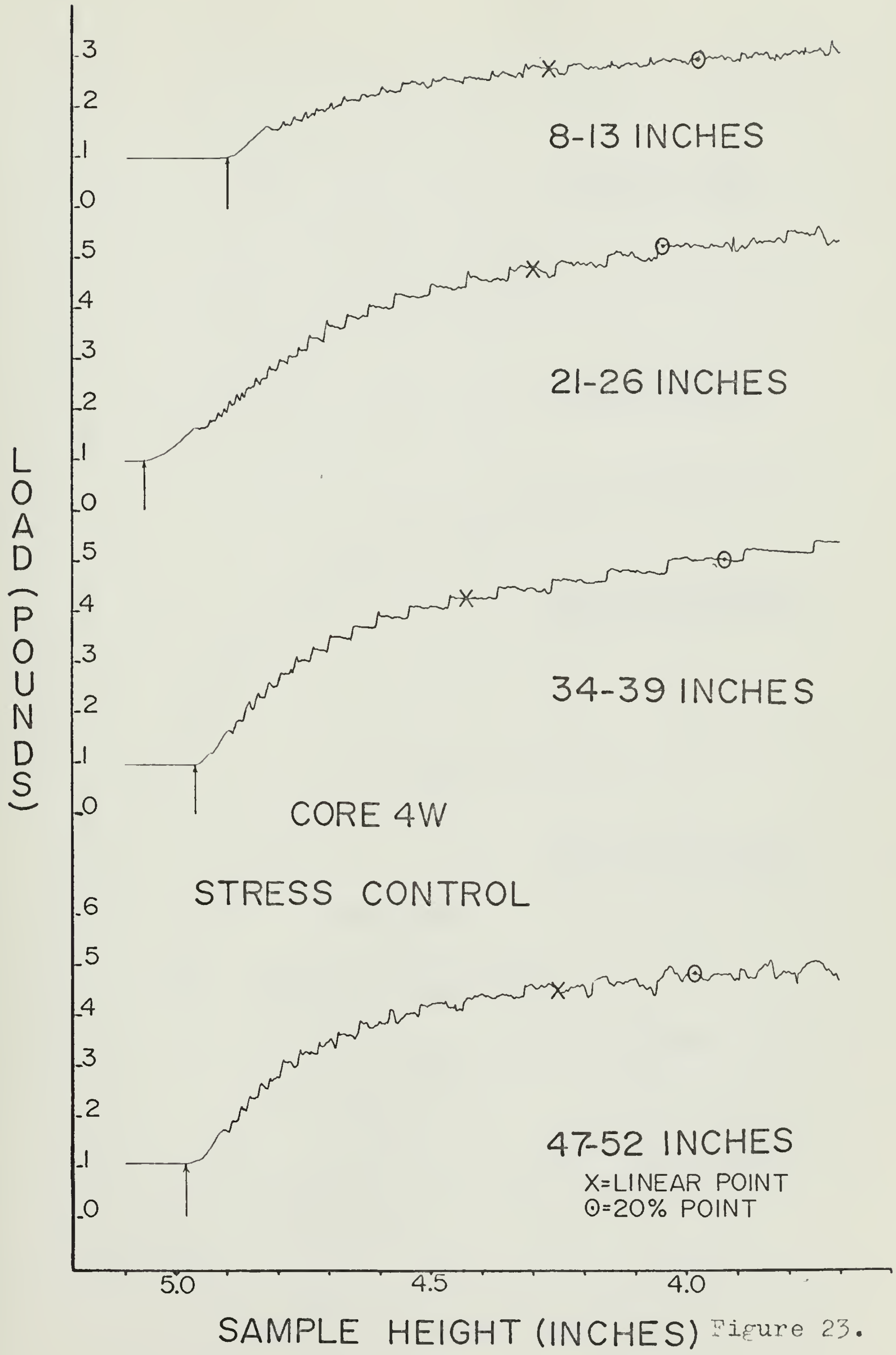

.3
.2
.1
.0
3-8 INCHES
.5
.4
.3
.2
.1
.0
16-21 INCHES
.6
.5
.4
.3
.2
.1
.0
29-34 INCHES
CORE 4W
STRAIN CONTROL
.6
.5
.4
.3
.2
.1
.0
42-47 INCHES
X=LINEAR POINT
O=20% POINT
LOAD (POUNDS)
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 22.



8-13 INCHES
21-26 INCHES
34-39 INCHES
47-52 INCHES
CORE 4W
STRESS CONTROL
X=LINEAR POINT
⊙=20% POINT
LOAD (POUNDS)
SAMPLE HEIGHT (INCHES)
.3
.2
.1
.0
.5
.4
.3
.2
.1
.0
.5
.4
.3
.2
.1
.0
.6
.5
.4
.3
.2
.1
.0
5.0
4.5
4.0

Figure 23.

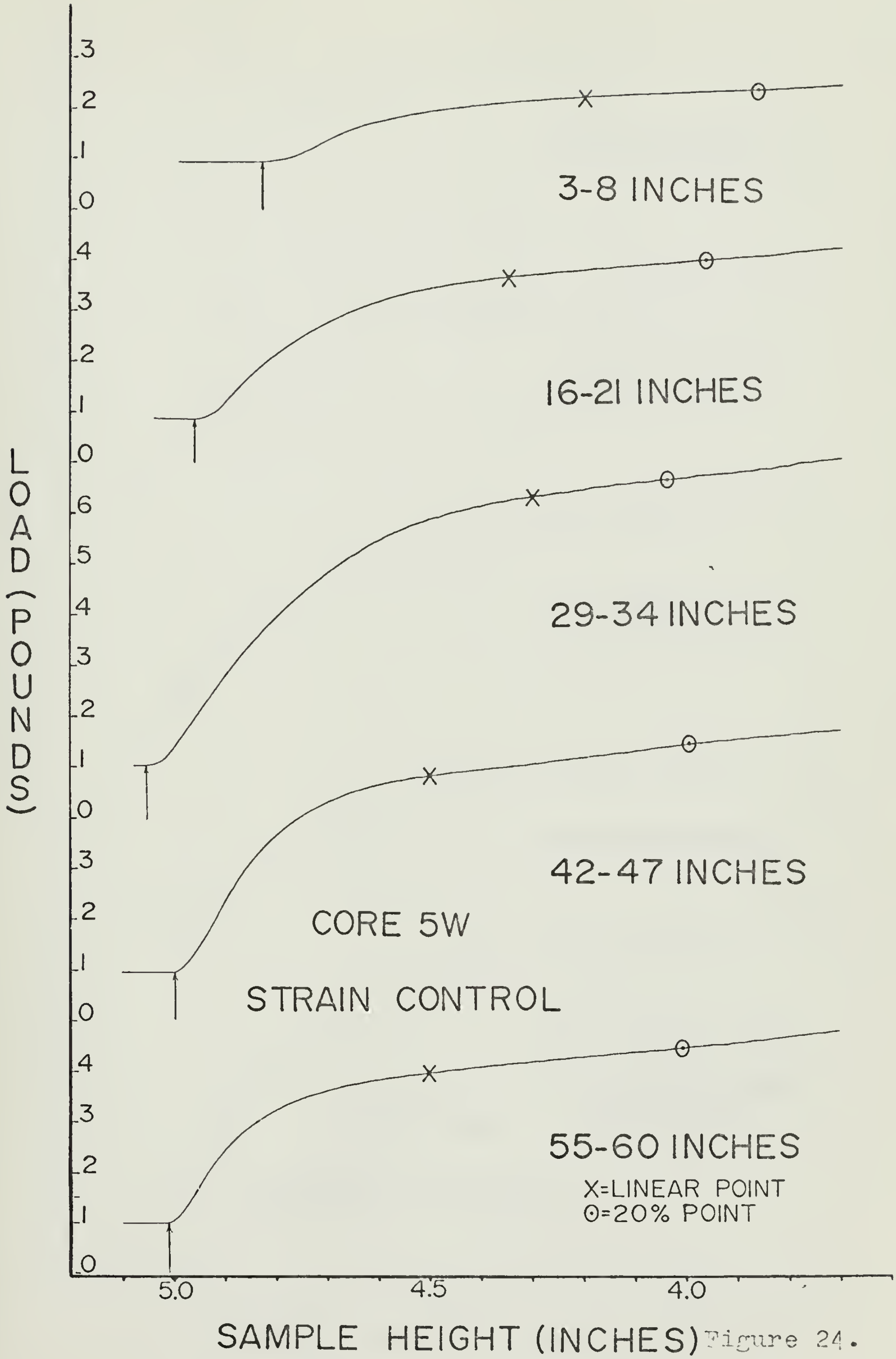
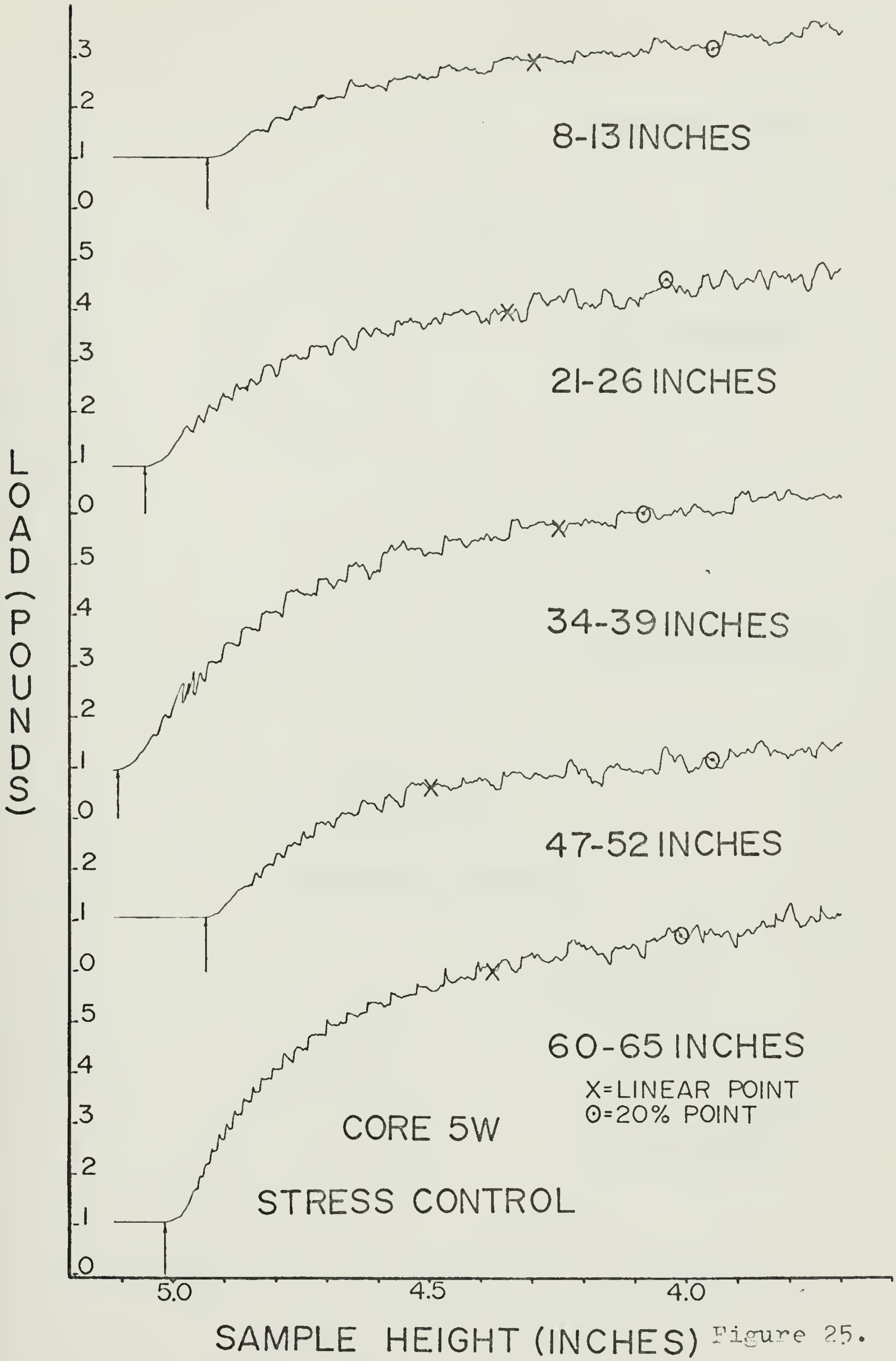
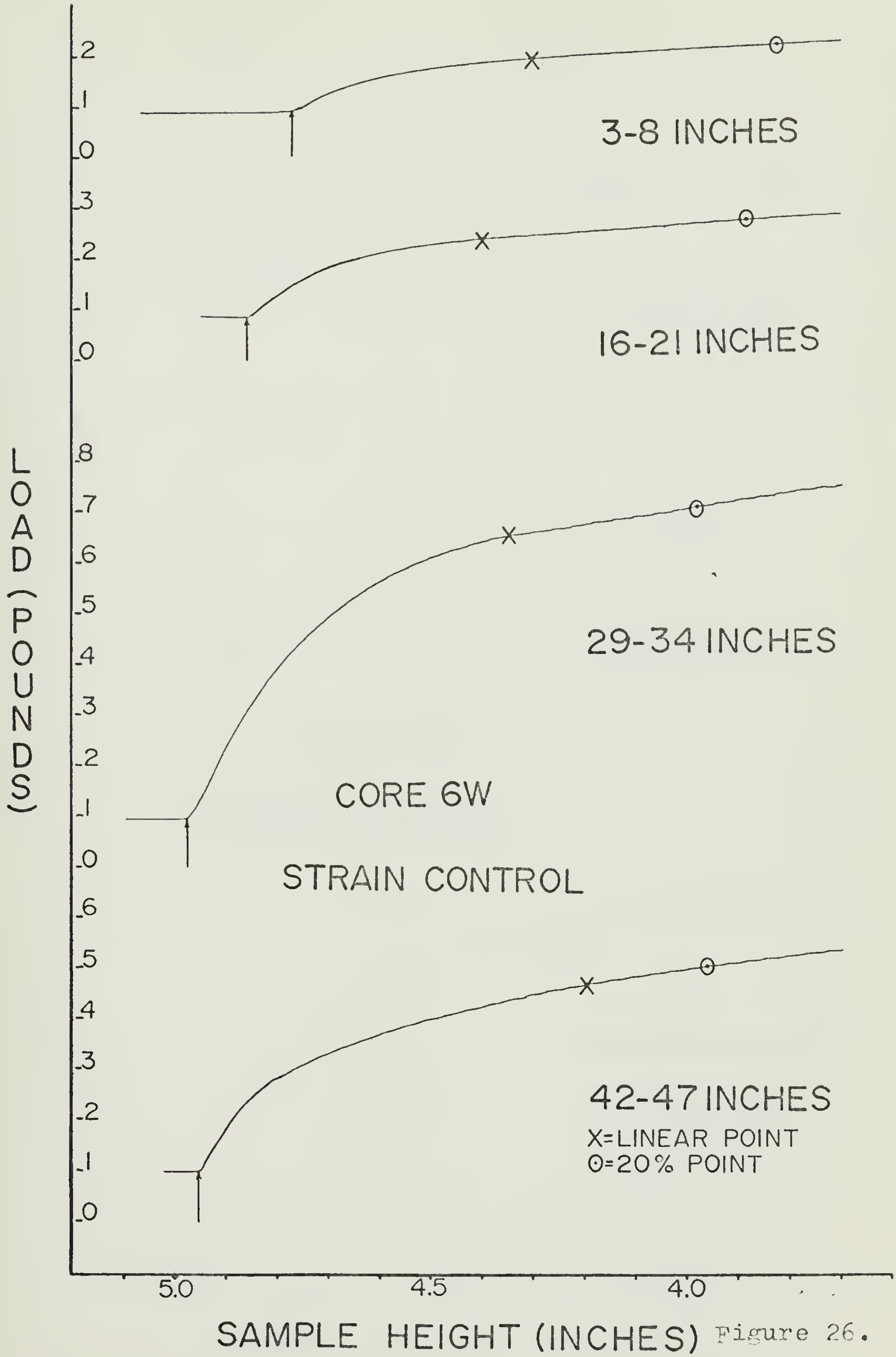

3-8 INCHES
16-21 INCHES
29-34 INCHES
42-47 INCHES
55-60 INCHES
CORE 5W
STRAIN CONTROL
X=LINEAR POINT
⊙=20% POINT
LOAD (POUNDS)
SAMPLE HEIGHT (INCHES)
5.0
4.5
4.0

Figure 24.



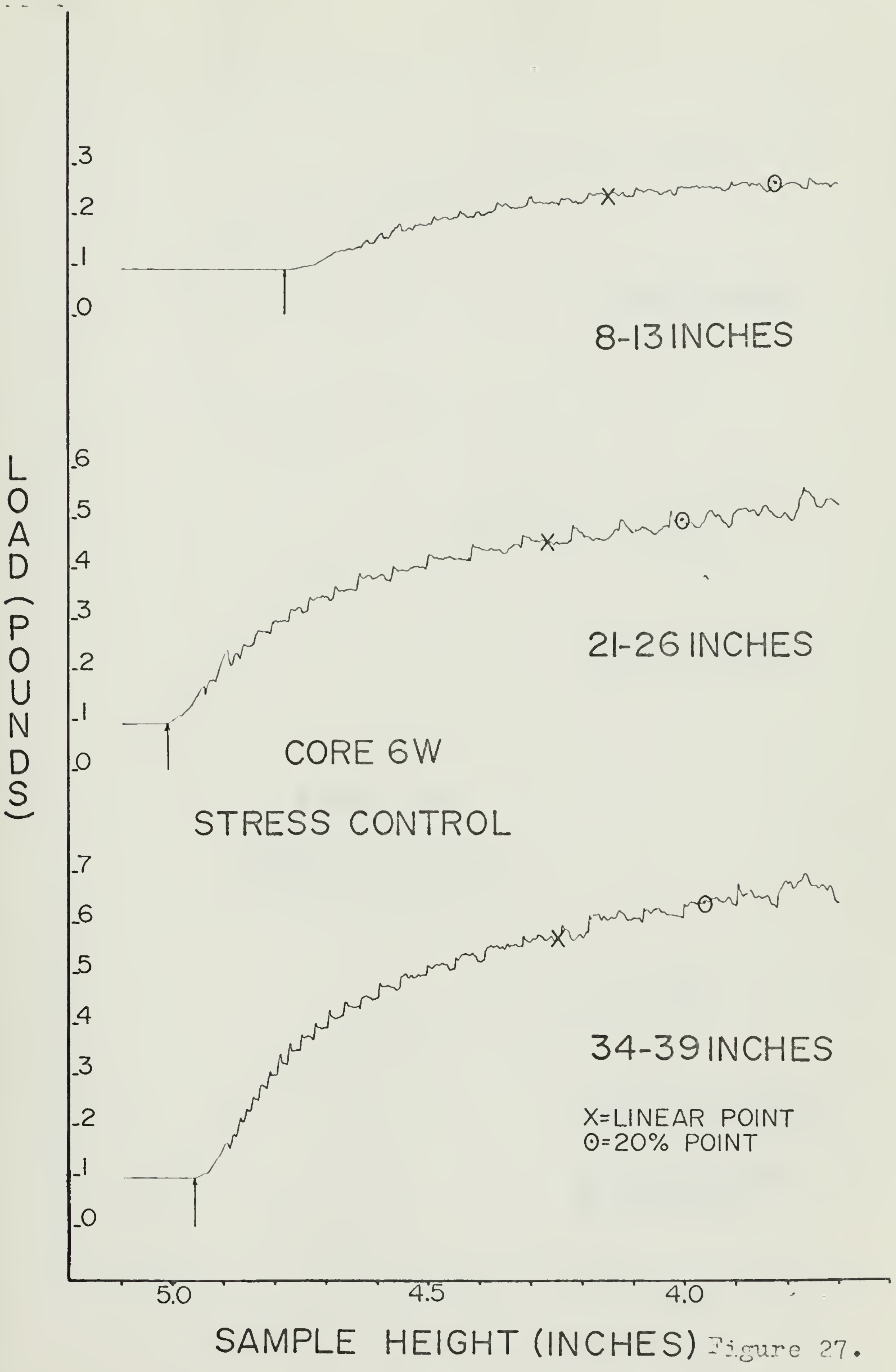
8-13 INCHES
21-26 INCHES
34-39 INCHES
47-52 INCHES
60-65 INCHES
X=LINEAR POINT
Θ=20% POINT
CORE 5W
STRESS CONTROL
LOAD (POUNDS)
SAMPLE HEIGHT (INCHES)
5.0
4.5
4.0

Figure 25.



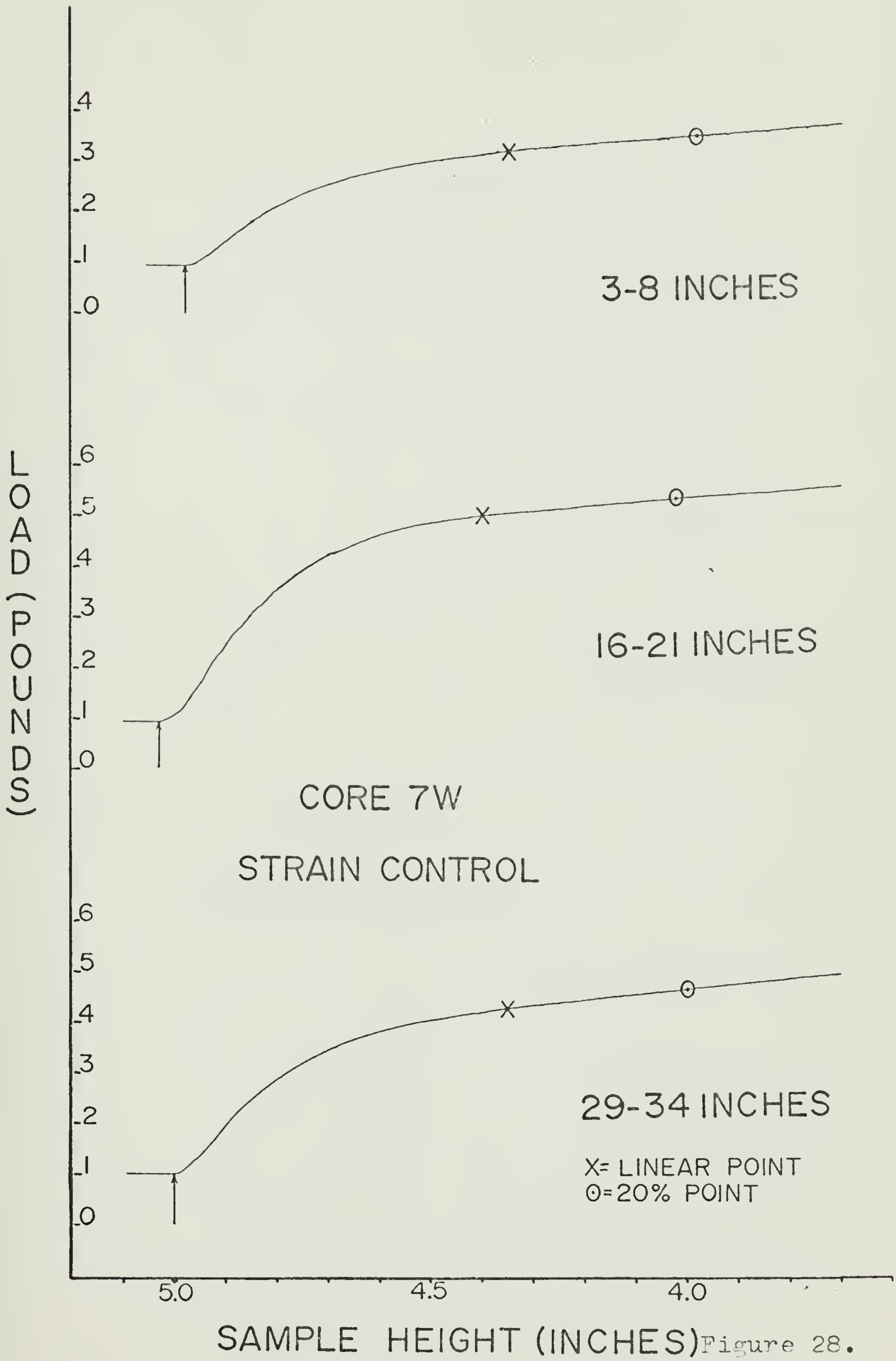
.2
.1
.0
.3
.2
.1
.0
3-8 INCHES
16-21 INCHES
.8
.7
.6
.5
.4
.3
.2
.1
.0
29-34 INCHES
CORE 6W
STRAIN CONTROL
.6
.5
.4
.3
.2
.1
.0
42-47 INCHES
X=LINEAR POINT
0=20% POINT
LOAD (POUNDS)
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 26.



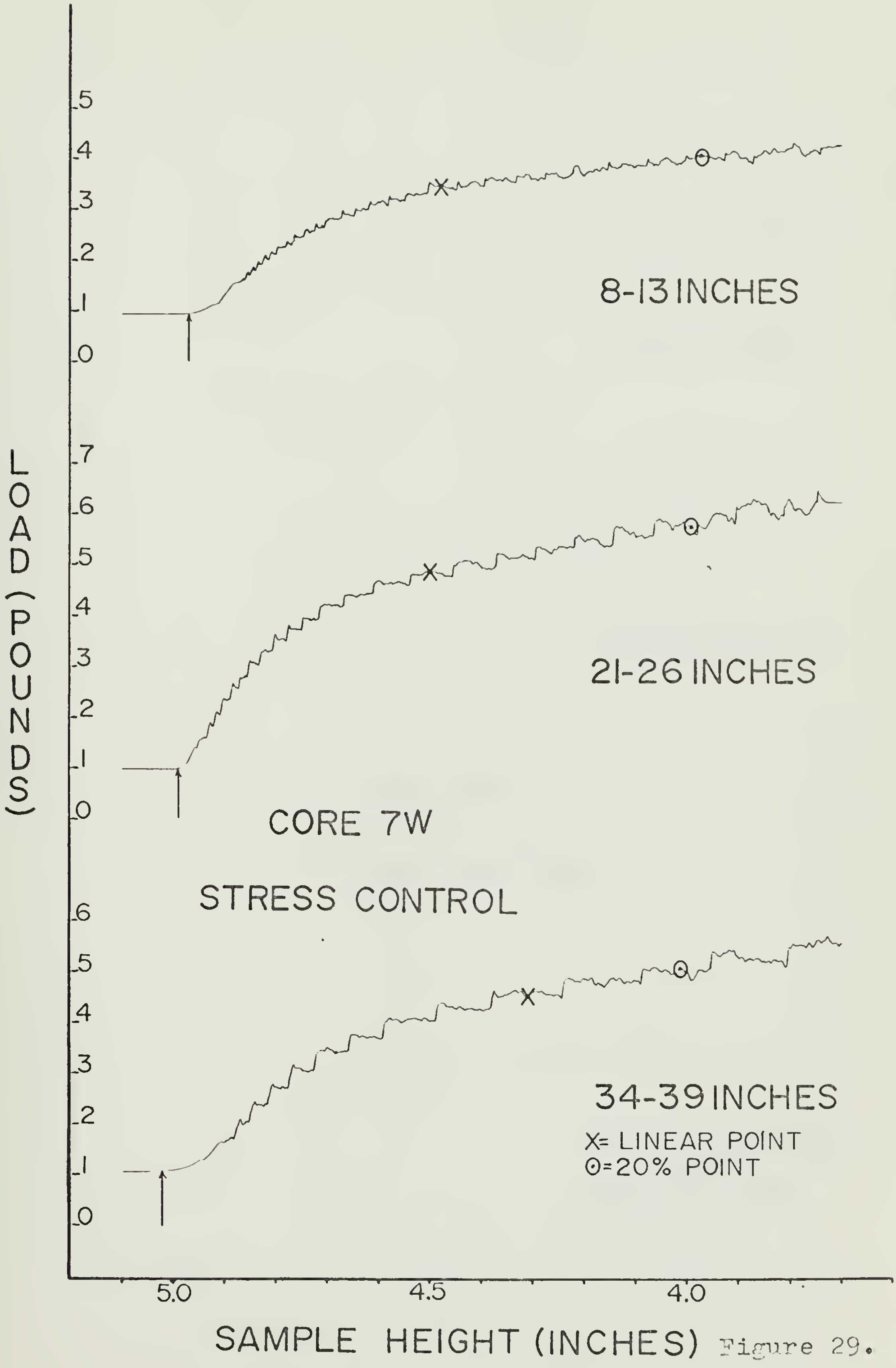
LOAD (POUNDS)
.3
.2
.1
.0
8-13 INCHES
.6
.5
.4
.3
.2
.1
.0
21-26 INCHES
CORE 6W
STRESS CONTROL
.7
.6
.5
.4
.3
.2
.1
.0
34-39 INCHES
X=LINEAR POINT
⊙=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 27.



LOAD (POUNDS)
.4
.3
.2
.1
.0
3-8 INCHES
.6
.5
.4
.3
.2
.1
.0
16-21 INCHES
CORE 7W
STRAIN CONTROL
.6
.5
.4
.3
.2
.1
.0
29-34 INCHES
X= LINEAR POINT
⊙=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 28.



LOAD (POUNDS)
.5
.4
.3
.2
.1
.0
8-13 INCHES
.7
.6
.5
.4
.3
.2
.1
.0
21-26 INCHES
CORE 7W
STRESS CONTROL
.6
.5
.4
.3
.2
.1
.0
34-39 INCHES
X= LINEAR POINT
O=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 29.

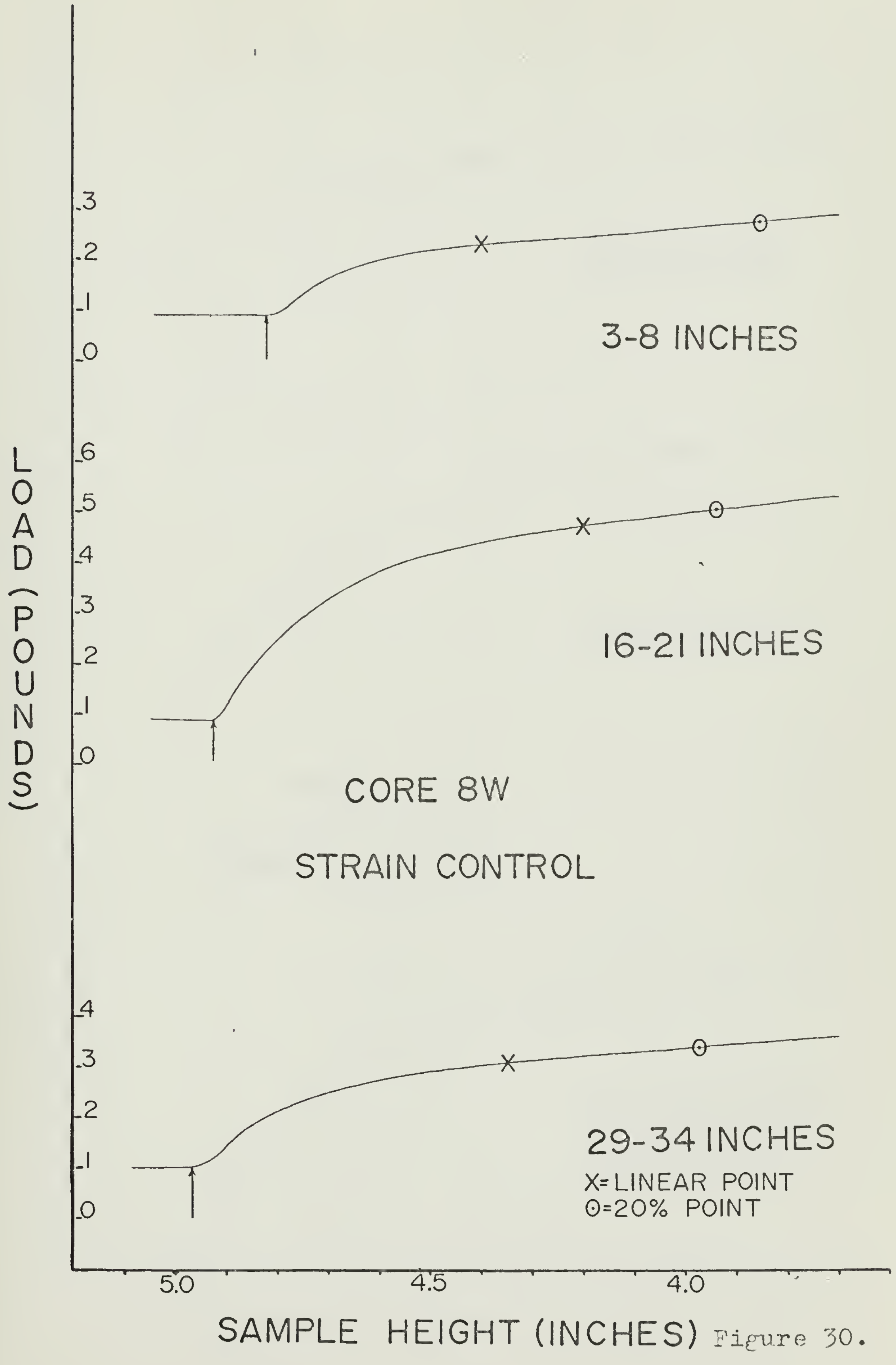
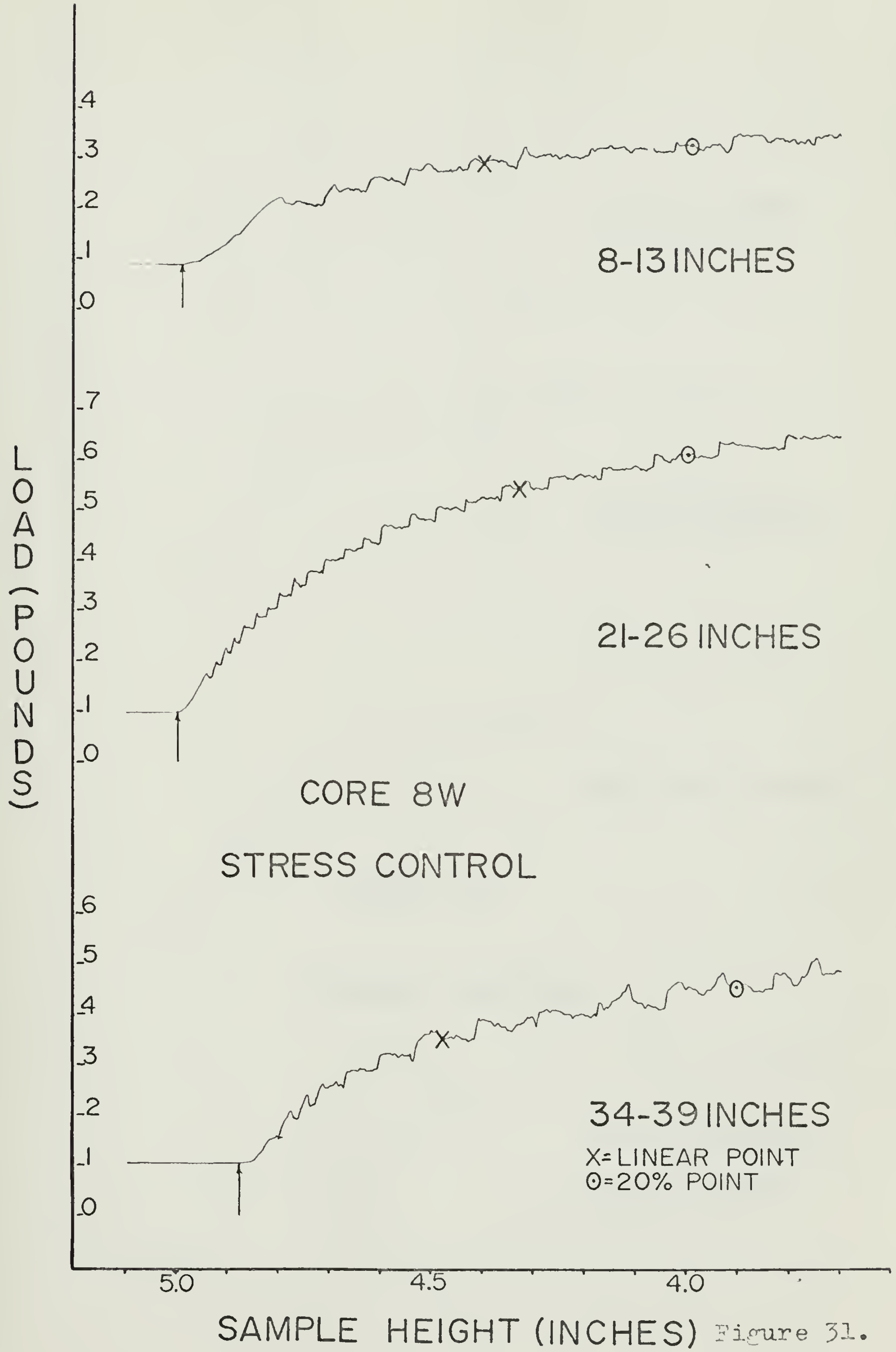

3-8 INCHES
16-21 INCHES
CORE 8W
STRAIN CONTROL
29-34 INCHES
X=LINEAR POINT
⊙=20% POINT
LOAD (POUNDS)
SAMPLE HEIGHT (INCHES)
5.0
4.5
4.0
.0
.1
.2
.3
.4
.5
.6

Figure 30.



.4
.3
.2
.1
.0
8-13 INCHES
.7
.6
.5
.4
.3
.2
.1
.0
21-26 INCHES
LOAD (POUNDS)
CORE 8W
STRESS CONTROL
.6
.5
.4
.3
.2
.1
.0
34-39 INCHES
X= LINEAR POINT
Θ=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 31.

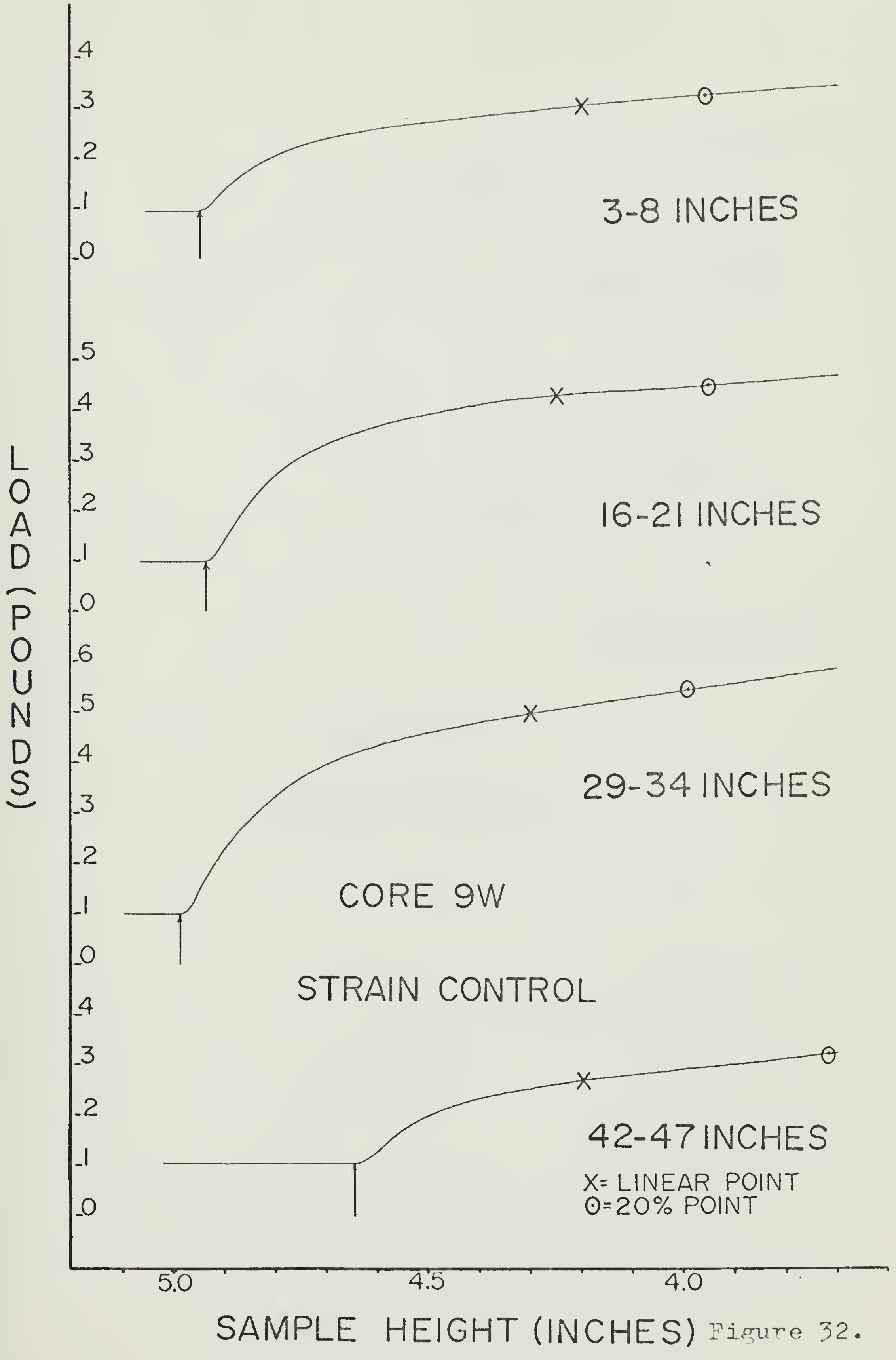

LOAD (POUNDS)
.4
.3
.2
.1
.0
3-8 INCHES
.5
.4
.3
.2
.1
.0
16-21 INCHES
.6
.5
.4
.3
.2
.1
.0
29-34 INCHES
CORE 9W
STRAIN CONTROL
.4
.3
.2
.1
.0
42-47 INCHES
X= LINEAR POINT
Θ=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 32.

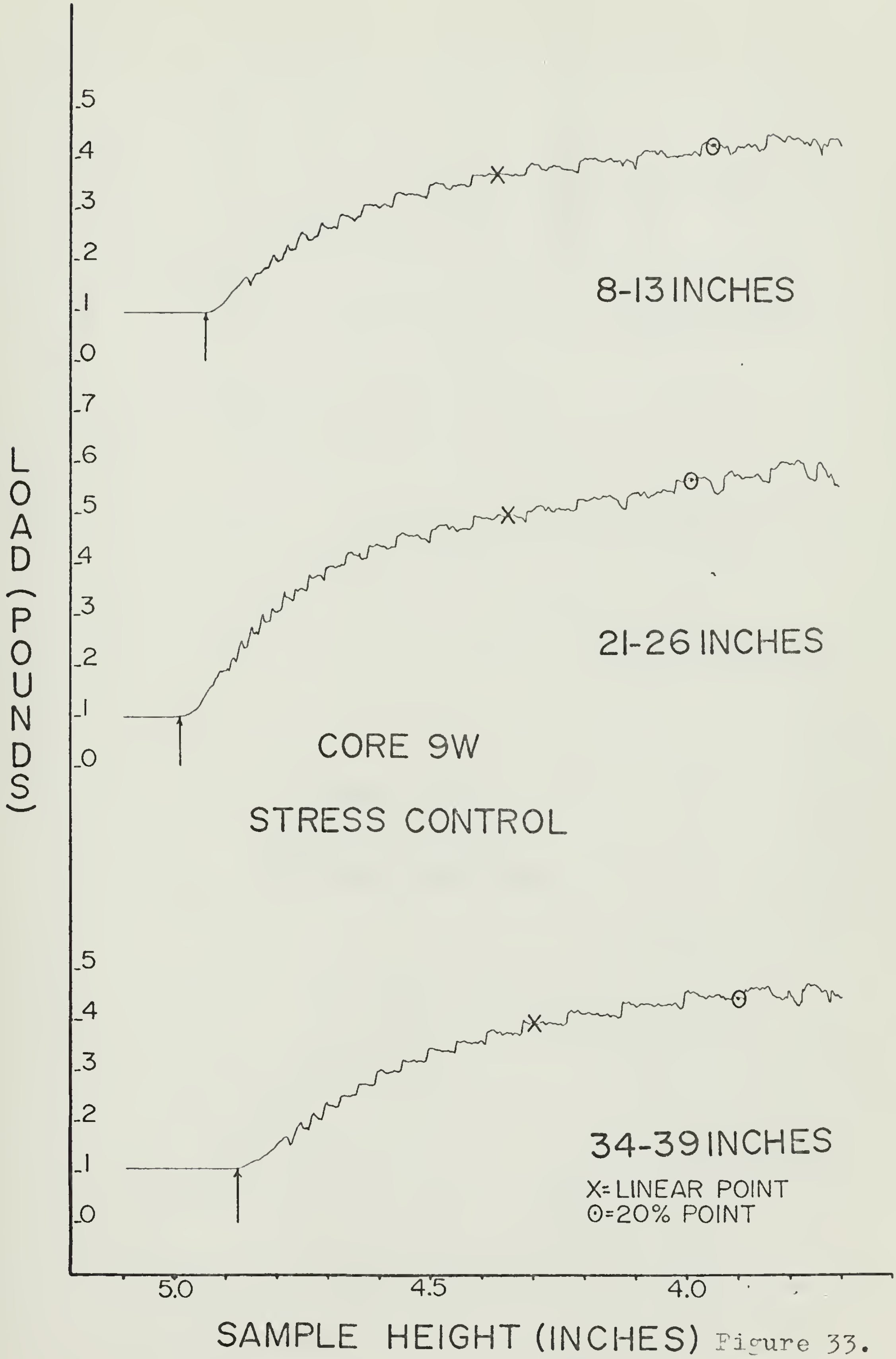
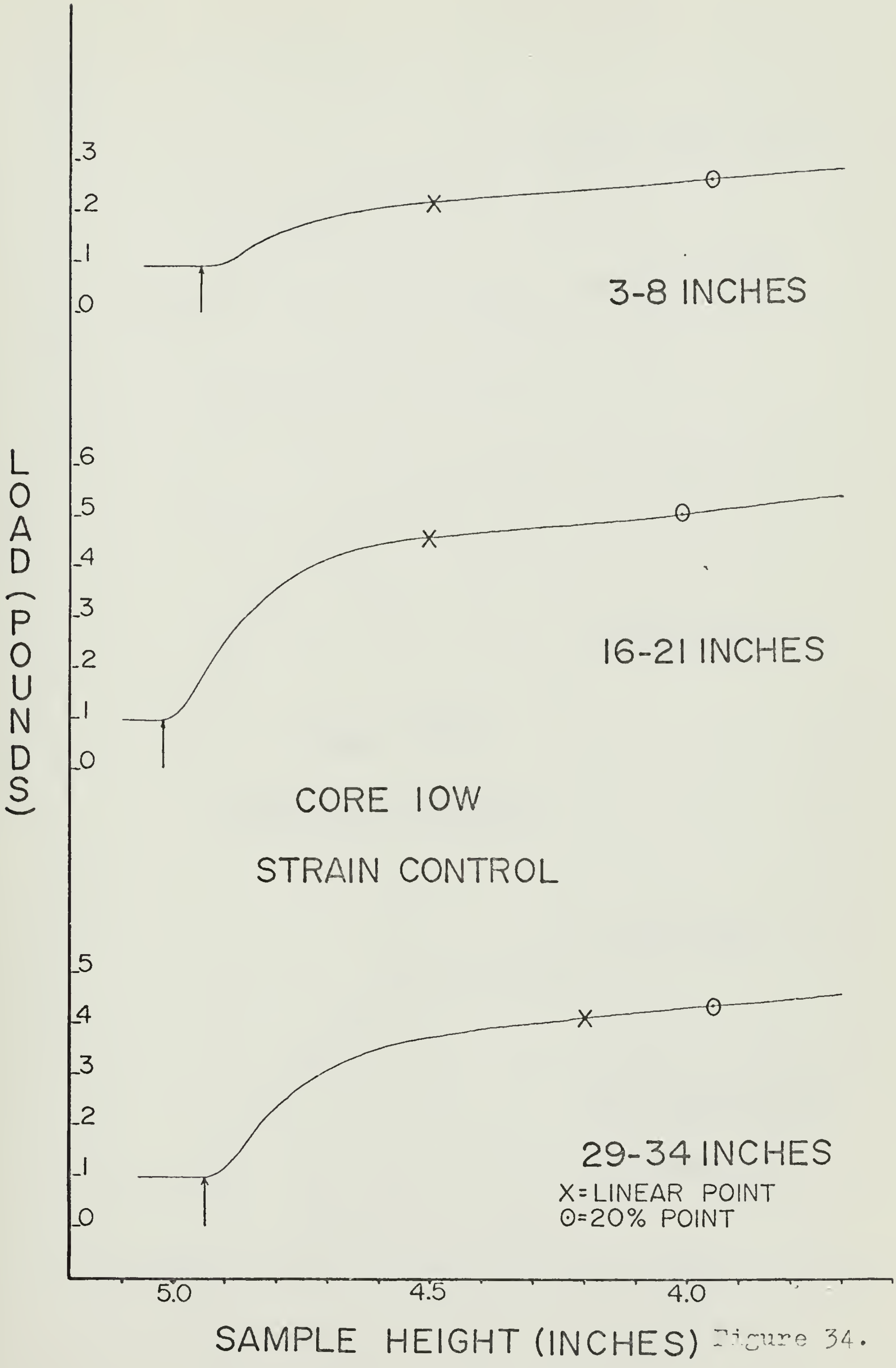
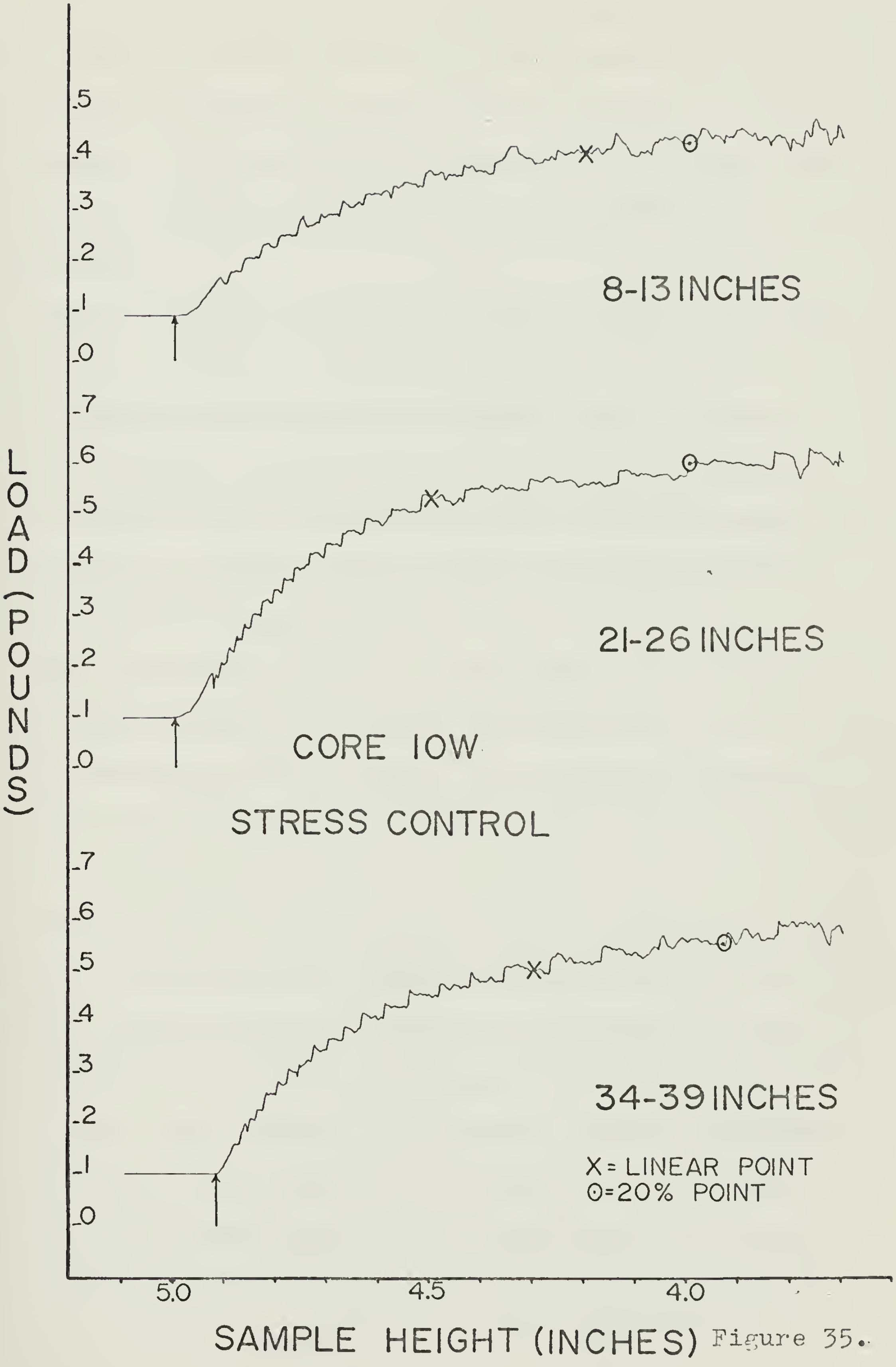

LOAD (POUNDS)
.5
.4
.3
.2
.1
.0
.7
.6
.5
.4
.3
.2
.1
.0
.5
.4
.3
.2
.1
.0
8-13 INCHES
21-26 INCHES
CORE 9W
STRESS CONTROL
34-39 INCHES
X= LINEAR POINT
⊙=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 33.



.3
.2
.1
.0
3-8 INCHES
.6
.5
.4
.3
.2
.1
.0
16-21 INCHES
LOAD (POUNDS)
CORE 10W
STRAIN CONTROL
.5
.4
.3
.2
.1
.0
29-34 INCHES
X=LINEAR POINT
⊙=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 34.



LOAD (POUNDS)
.5
.4
.3
.2
.1
.0
8-13 INCHES
.7
.6
.5
.4
.3
.2
.1
.0
21-26 INCHES
CORE 10W
STRESS CONTROL
.7
.6
.5
.4
.3
.2
.1
.0
34-39 INCHES
X= LINEAR POINT
⊙=20% POINT
5.0
4.5
4.0
SAMPLE HEIGHT (INCHES)

Figure 35.

Two shear strength computations were made. The first included the sample weight as part of the load value and the second neglected the sample weight. This was done to ascertain the effect of sample weight on the shear strength determination. The values of linear strength and the strain at which the linear point occurred are both listed for each sediment sample in Table II through Table XI.

Using the initial sample height as indicated on the load - sample height curve, a 20 percent displacement height was computed and this point was also marked on the curve as the "20 percent point." Two shear strength values were computed using the values of load and sample displacement at this "20 percent point," one without the sample weight and one with the weight included. Tabulated results of these calculations are also included in Table II through Table XI.

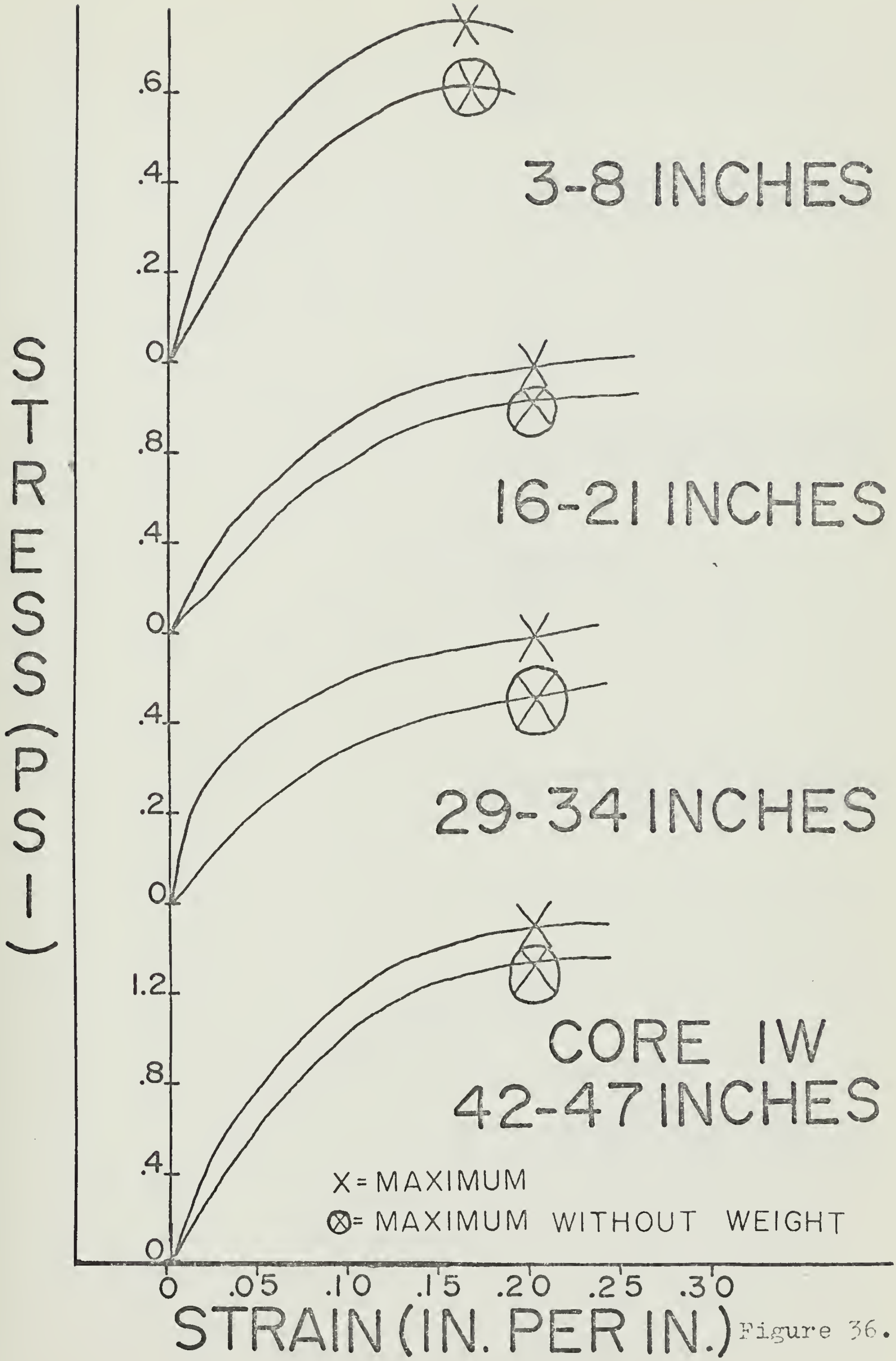
Close examination of the load - sample height curves of Figure 16 through Figure 35 shows that extremely smooth curves are made when conducting the strain-controlled mode of testing. Load and sample displacement values from these curves gave calculated results producing smooth stress - strain curves.

Curves made in the stress-controlled mode of testing produced different results. Due to friction losses and because a portion of the load was required to move the displacement transducer end probe, the weight of the load increment was not entirely transmitted to the sample. This is shown on the curves. Also, between load increments, there were many changes in the load applied to the sample caused by either friction or sample shear. Vibrations of the machine and electrical interference from surrounding equipment were not involved. This was indicated by the initial smooth portion of the curve where only the sample weight was recorded as the weighted piston assembly was lowered to contact the sample.

The frictional losses come from two sources. The first involves the contact between the weighted piston shaft and the ball bushing. A second source, considered negligible, results from the movement of the displacement transducer end probe. The ball bushing was specifically used on the machine to minimize friction loss and is considered to be the best practical arrangement. Incremental shearing of the sample produced the remaining changes in load and this shearing is uniquely depicted on the load versus sample height recordings. In some cases this shearing was physically observed. The fact that the load unpredictably did change, sometimes as much as the load increment itself, caused greater point scatter on the stress versus strain curves during testing. This results in a reduced accuracy of the shear strength value in the stress-controlled mode of testing.

The stress-strain curves shown in Figure 36 through Figure 55 were plotted, following standard practice. Each figure contains the curves for the samples of that core which were tested in a similar mode. Values of stress and strain were calculated at every 1/10-inch displacement of sample height. Two curves were plotted for each sediment sample. The upper curve includes the sample weight in the stress calculations, whereas the lower curve neglects the sample weight. Faired curves were drawn through the plotted points. The maximum stress value on each curve is marked. Shear strength calculations were made using the maximum stress on the stress-strain curve and includes sample weight. These maximum shear strengths and the percent strain at which they occurred are listed in Table II through Table XI.

The stress-strain curves plotted in Figures 36 through 55 all show the general tendency of leveling off to a constant value of stress. There were only two curves that dropped off sharply in classic manner. The first



3-8 INCHES
16-21 INCHES
29-34 INCHES
CORE IW
42-47 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
STRESS (PSI)
STRAIN (IN. PER IN.)
.6
.4
.2
0
.8
.4
0
.4
.2
0
1.2
.8
.4
0
0
.05
.10
.15
.20
.25
.30

Figure 36.

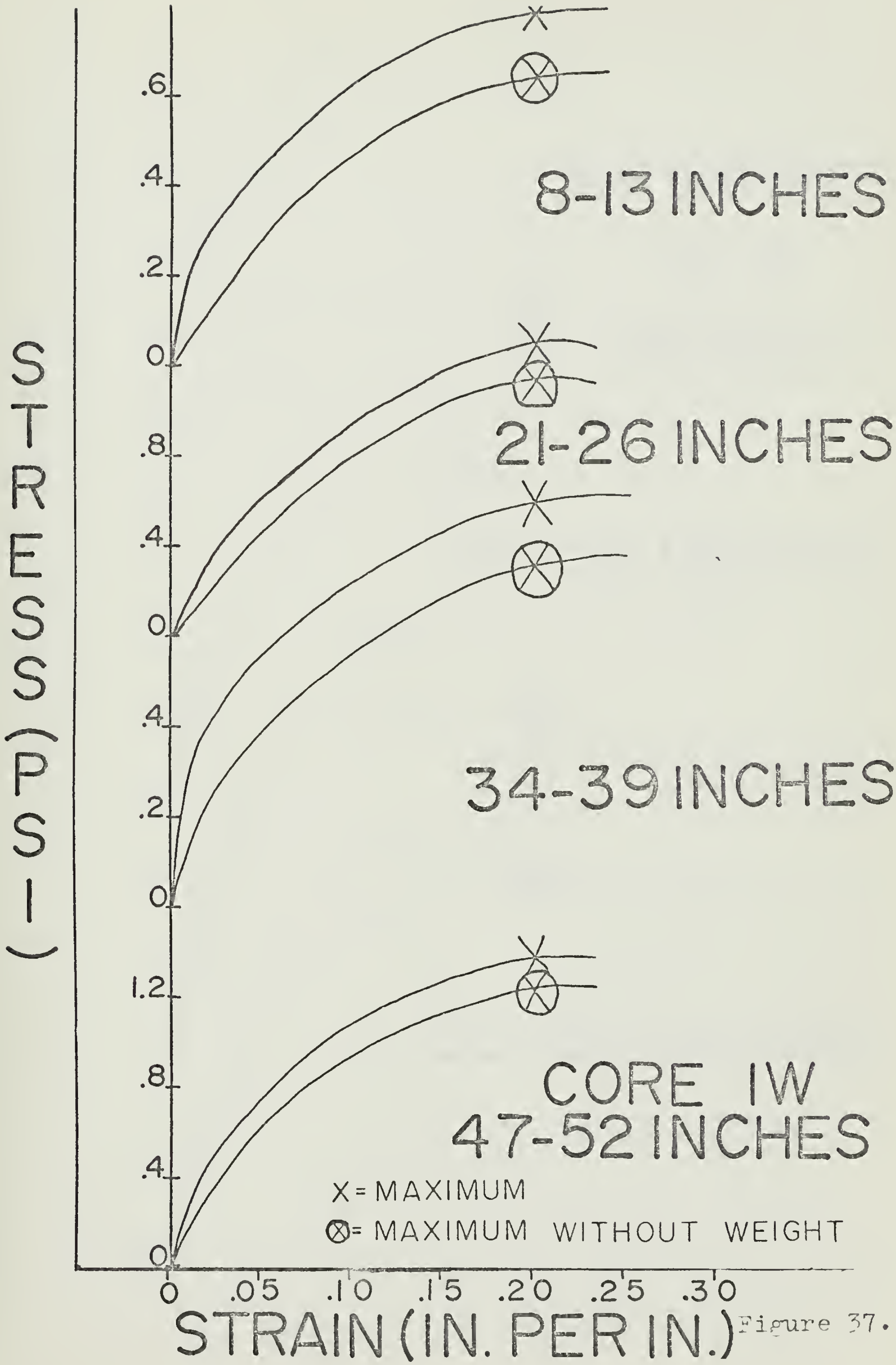

STRESS (PSI)
.6
.4
.2
0
8-13 INCHES
.8
.4
0
21-26 INCHES
.4
.2
0
34-39 INCHES
1.2
.8
.4
0
CORE IW
47-52 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 37.

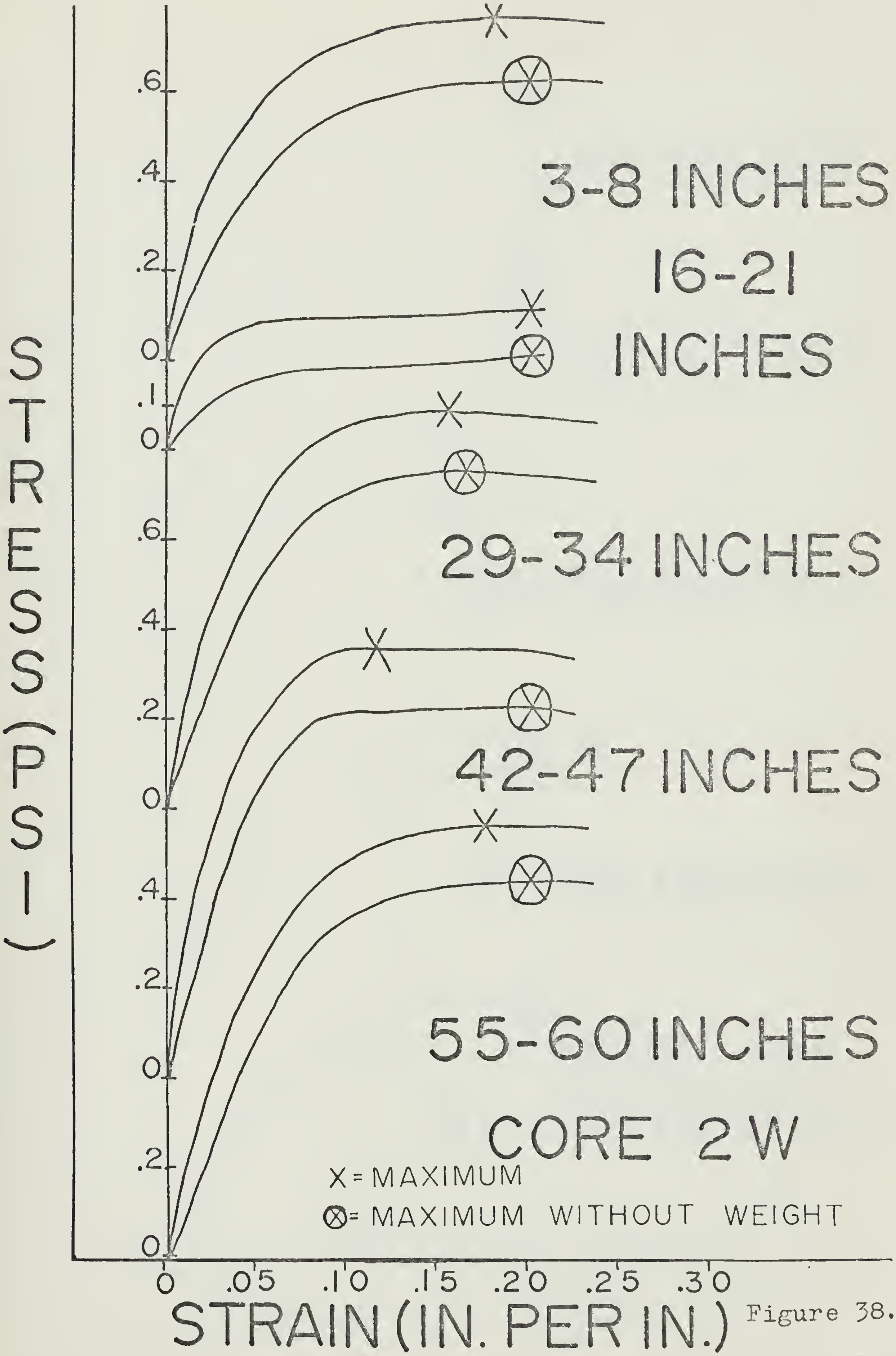
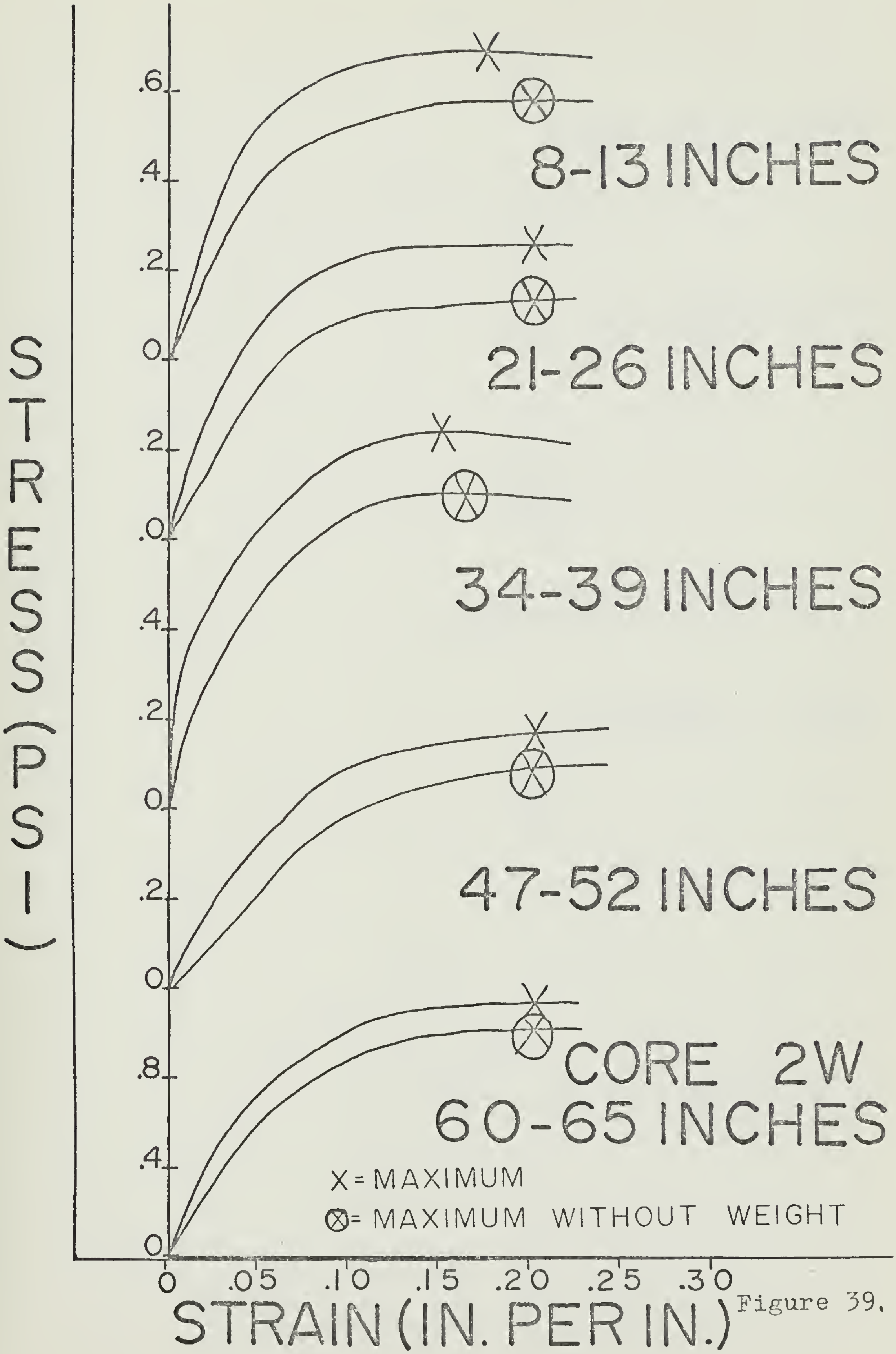

3-8 INCHES
16-21 INCHES
29-34 INCHES
42-47 INCHES
55-60 INCHES
CORE 2W
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
STRESS (PSI)
STRAIN (IN. PER IN.)
0
.05
.10
.15
.20
.25
.30
.2
.4
.6
.1

Figure 38.


8-13 INCHES
21-26 INCHES
34-39 INCHES
47-52 INCHES
CORE 2W
60-65 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
STRESS (PSI)
STRAIN (IN. PER IN.)
.6
.4
.2
0
.2
.0
.4
.2
0
.2
0
.8
.4
0
0
.05
.10
.15
.20
.25
.30
Figure 39.

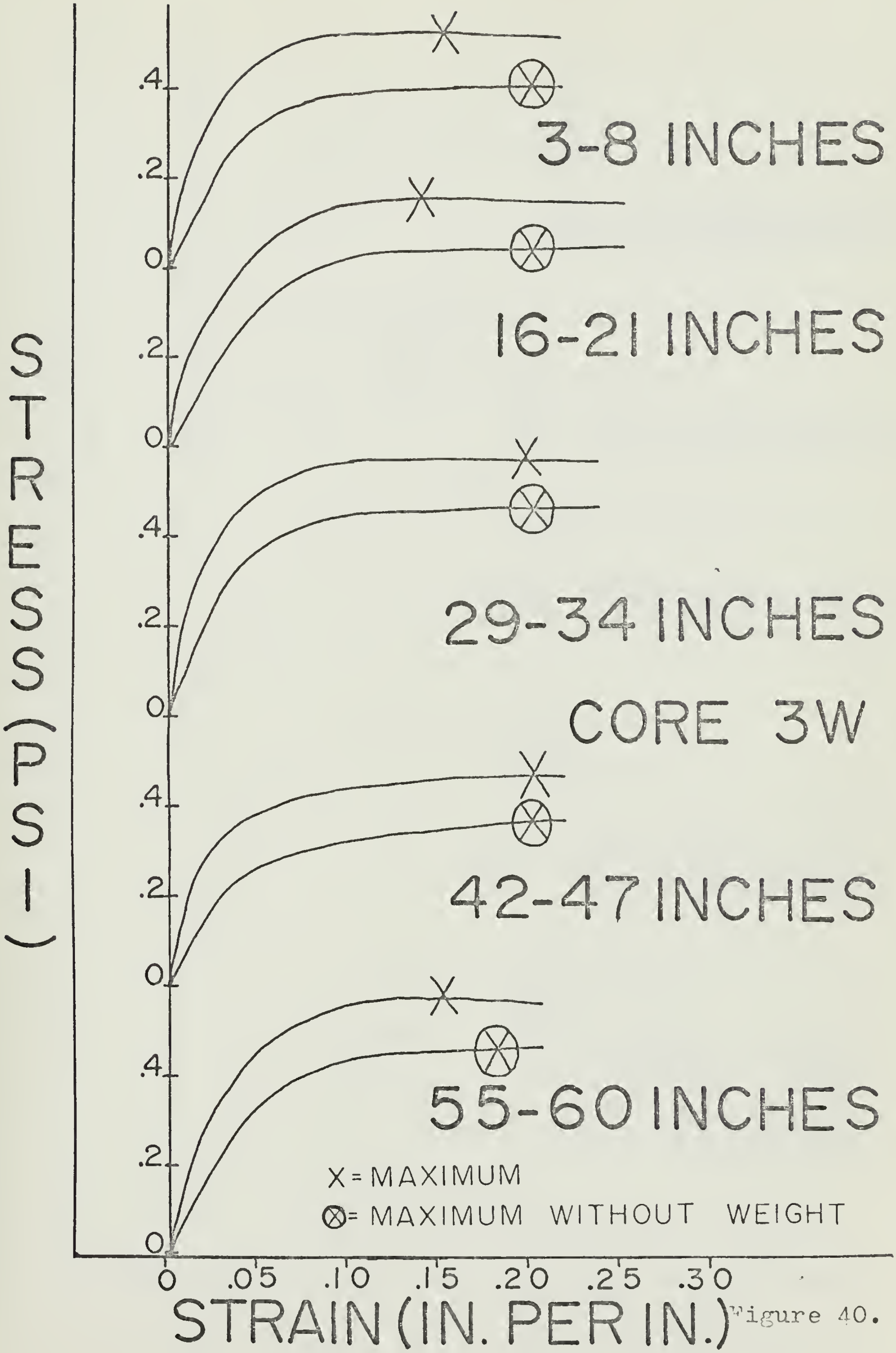
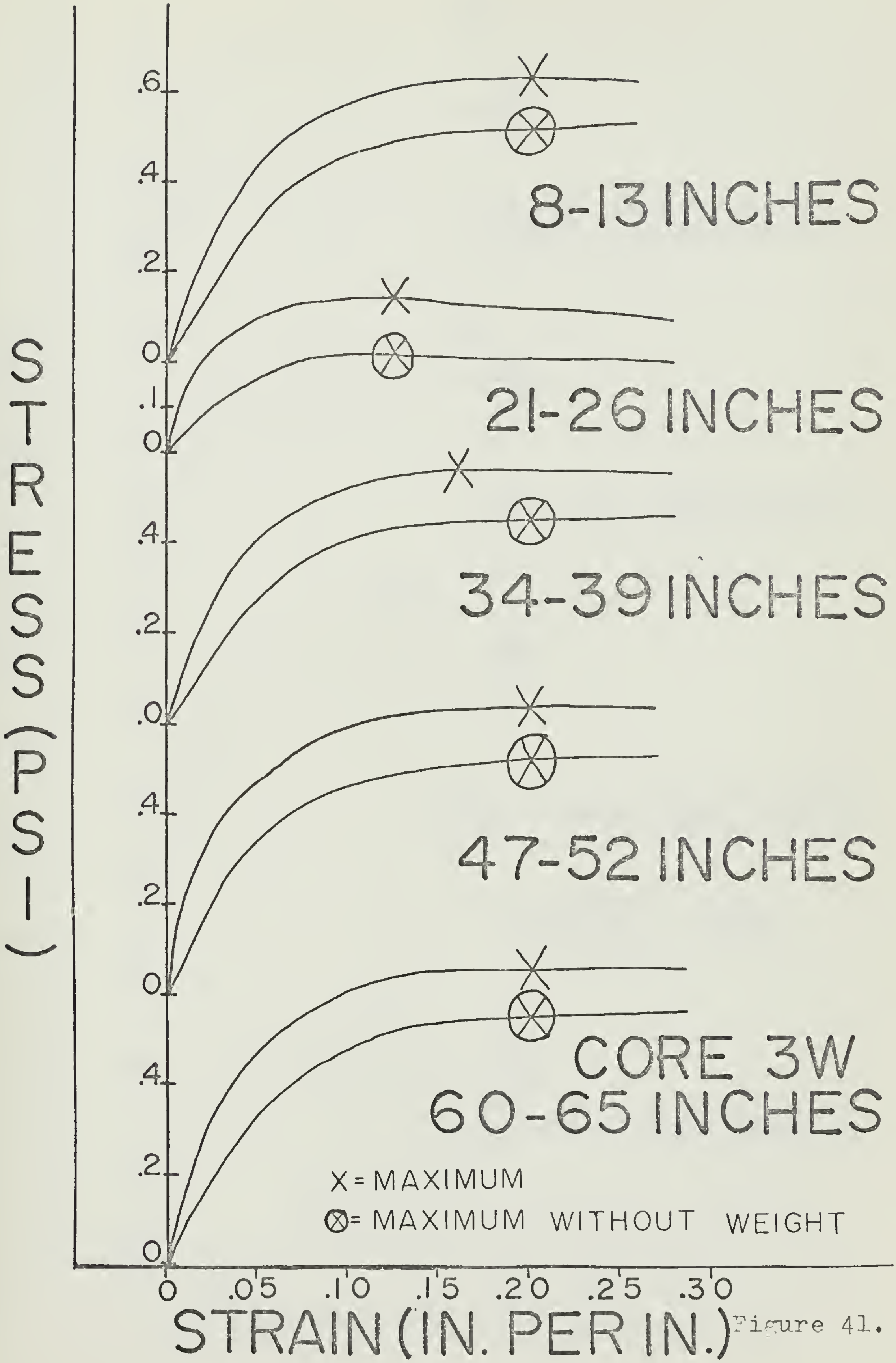
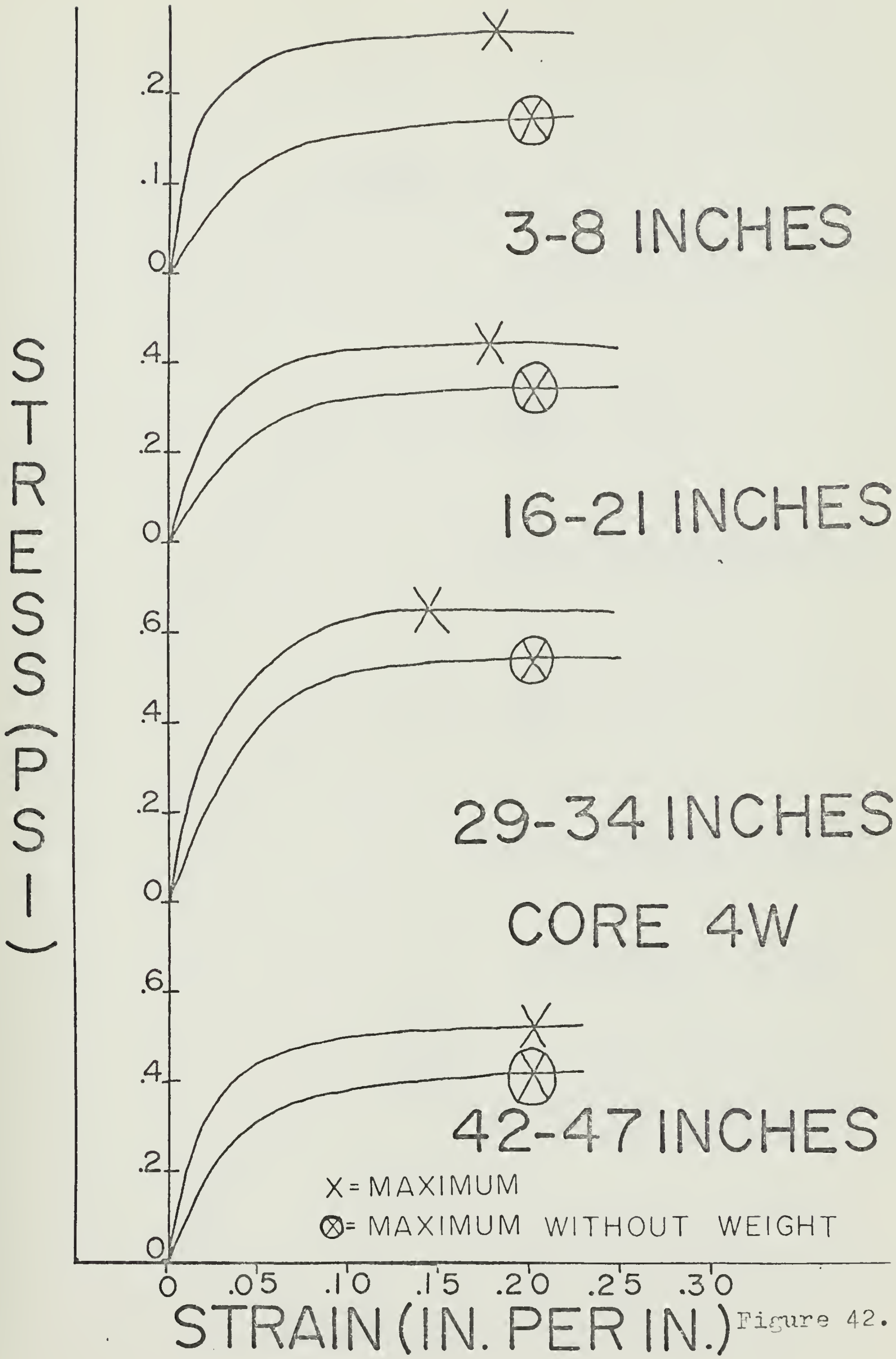

3-8 INCHES
16-21 INCHES
29-34 INCHES
CORE 3W
42-47 INCHES
55-60 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
STRESS (PSI)
STRAIN (IN. PER IN.)
.4
.2
0
0
.05
.10
.15
.20
.25
.30

Figure 40.



STRESS (PSI)
.6
.4
.2
0
.1
0
.4
.2
.0
.4
.2
0
.4
.2
0
8-13 INCHES
21-26 INCHES
34-39 INCHES
47-52 INCHES
CORE 3W
60-65 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 41.


STRESS (PSI)
.2
.1
0
3-8 INCHES
.4
.2
0
16-21 INCHES
.6
.4
.2
0
29-34 INCHES
CORE 4W
.6
.4
.2
0
42-47 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0 .05 .10 .15 .20 .25 .30
STRAIN (IN. PER IN.)
Figure 42.

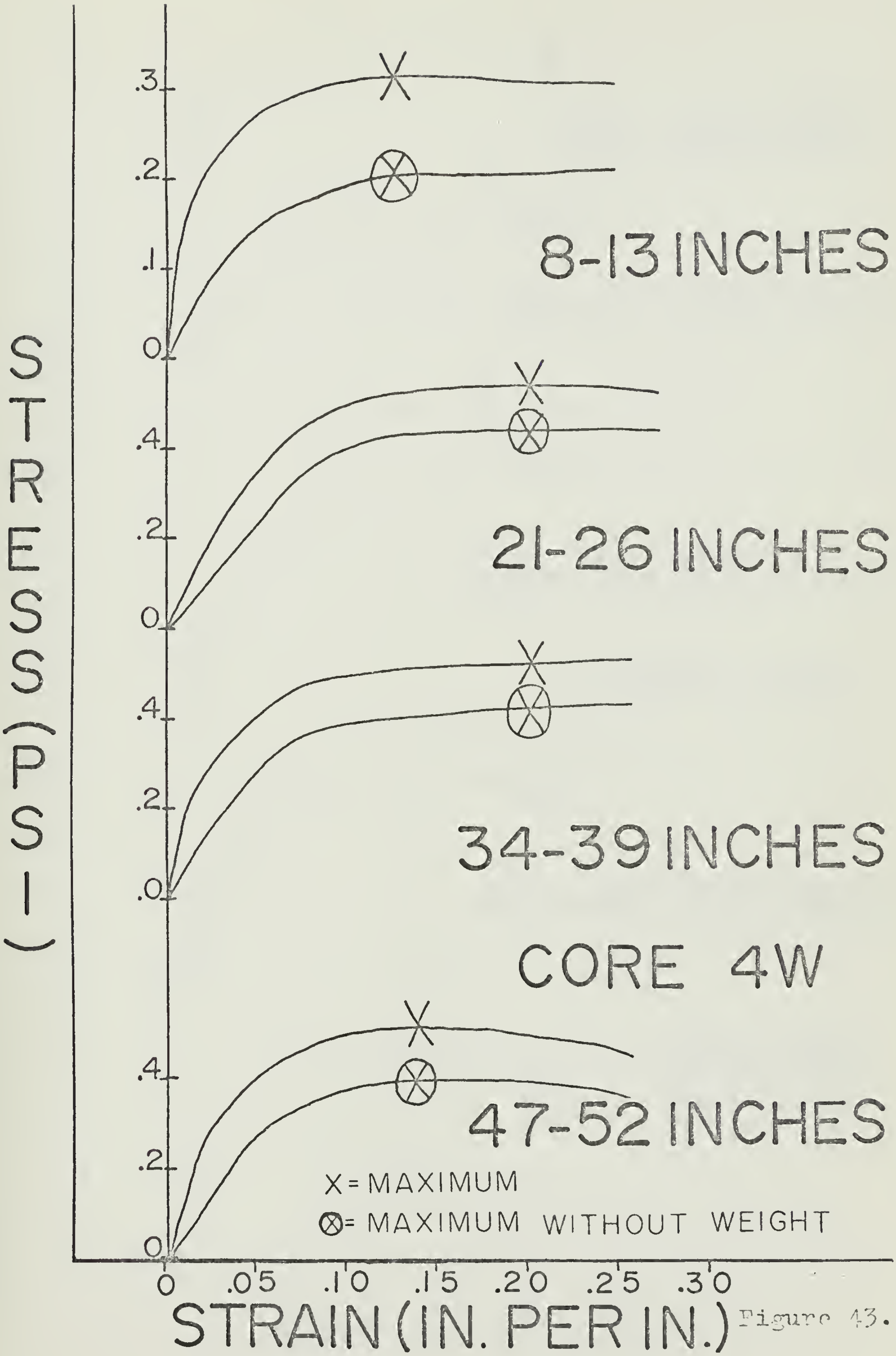
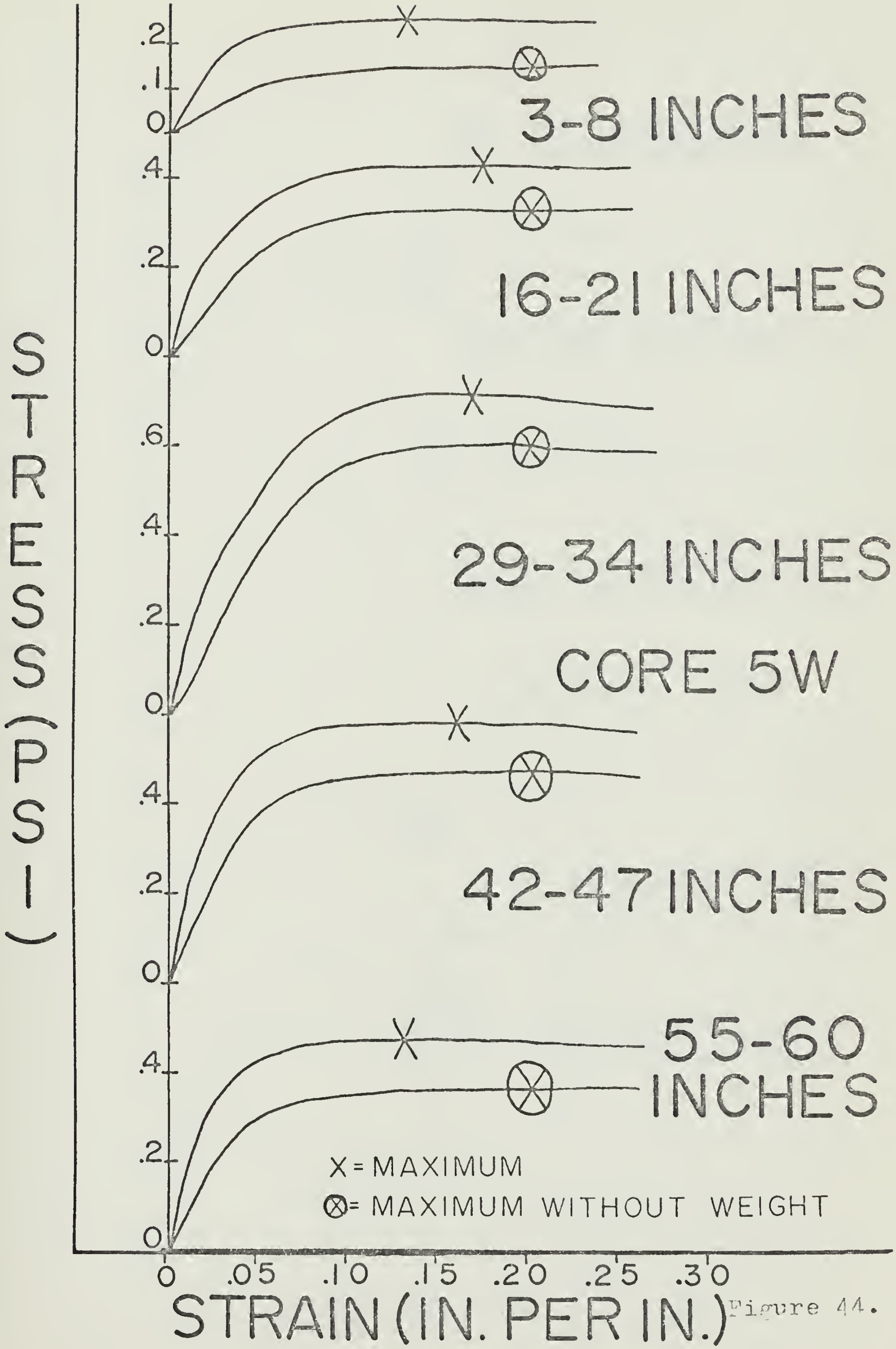

STRESS (PSI)
.3
.2
.1
0
.4
.2
0
.4
.2
.0
.4
.2
0
8-13 INCHES
21-26 INCHES
34-39 INCHES
CORE 4W
47-52 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 43.



STRESS (PSI)
STRAIN (IN. PER IN.)
3-8 INCHES
16-21 INCHES
29-34 INCHES
CORE 5W
42-47 INCHES
55-60 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
.2
.1
0
.4
.6

Figure 44.

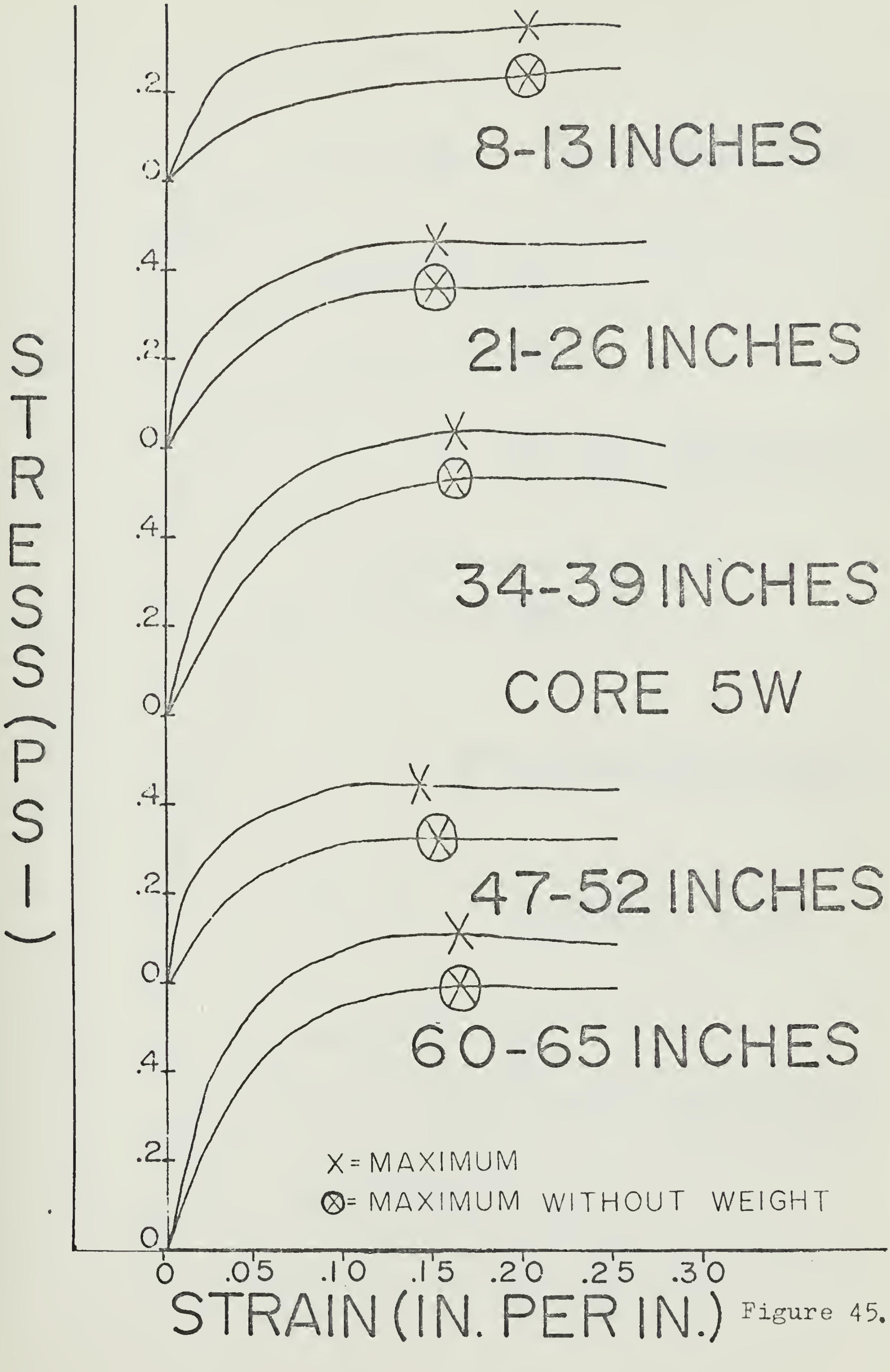
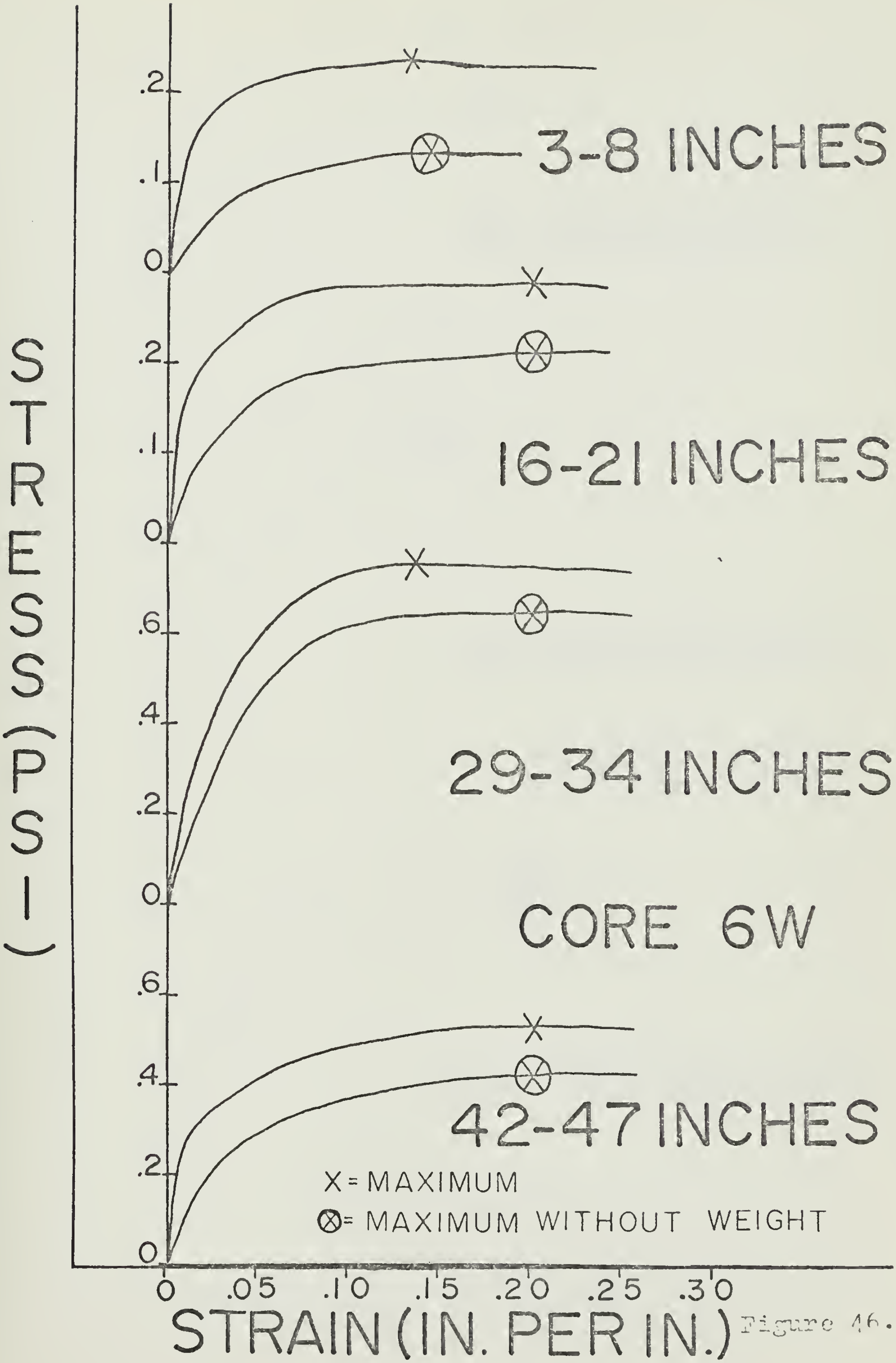
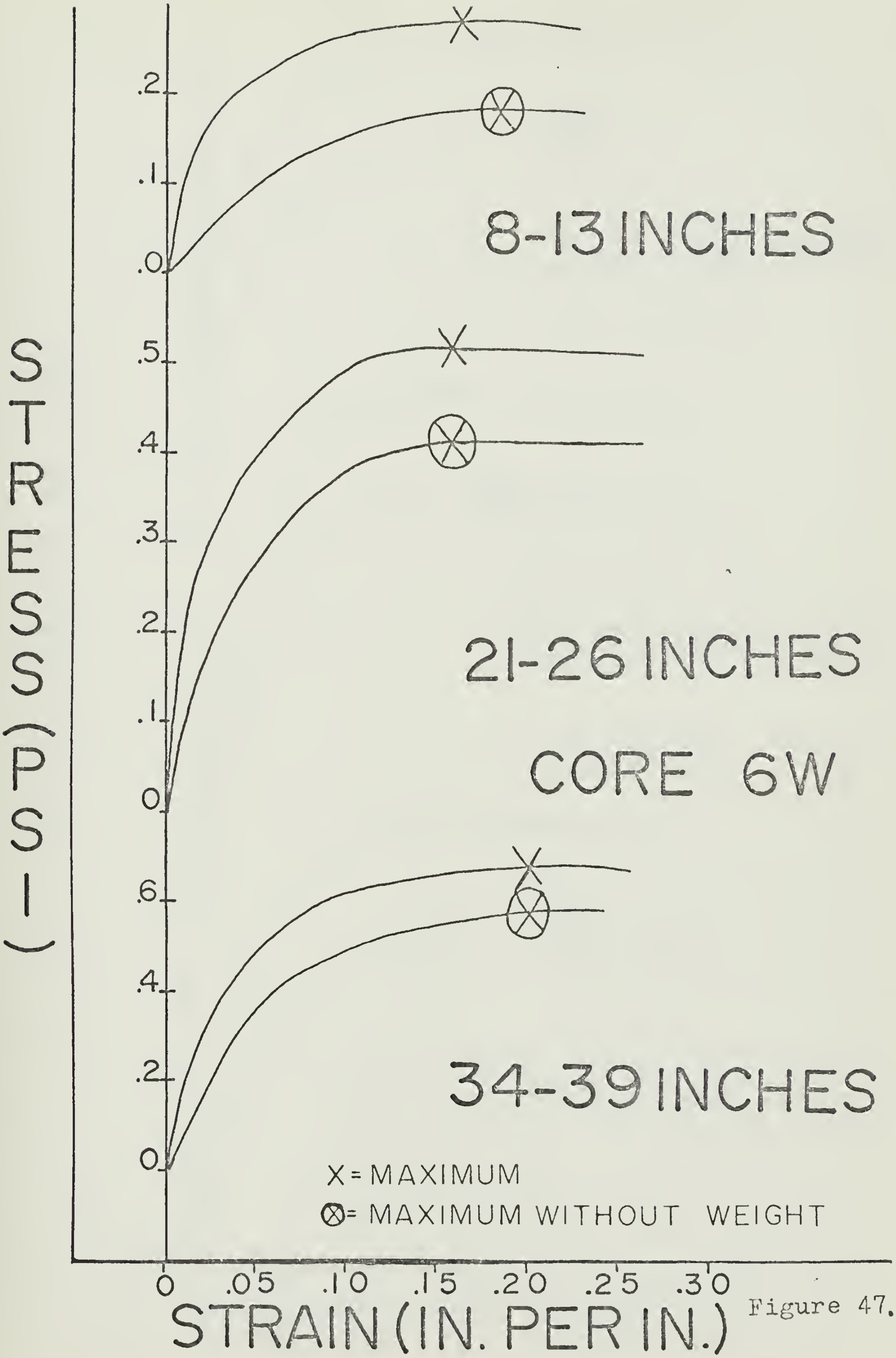

8-13 INCHES
21-26 INCHES
34-39 INCHES
CORE 5W
47-52 INCHES
60-65 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
STRESS (PSI)
STRAIN (IN. PER IN.)
0
.2
.4
0
.05
.10
.15
.20
.25
.30

Figure 45.



STRESS (PSI)
.2
.1
0
3-8 INCHES
.2
.1
0
16-21 INCHES
.6
.4
.2
0
29-34 INCHES
CORE 6W
.6
.4
.2
0
42-47 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0 .05 .10 .15 .20 .25 .30
STRAIN (IN. PER IN.)

Figure 46.



STRESS (PSI)
.2
.1
.0
.5
.4
.3
.2
.1
0
.6
.4
.2
0
8-13 INCHES
21-26 INCHES
CORE 6W
34-39 INCHES
X = MAXIMUM
⊗= MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 47.

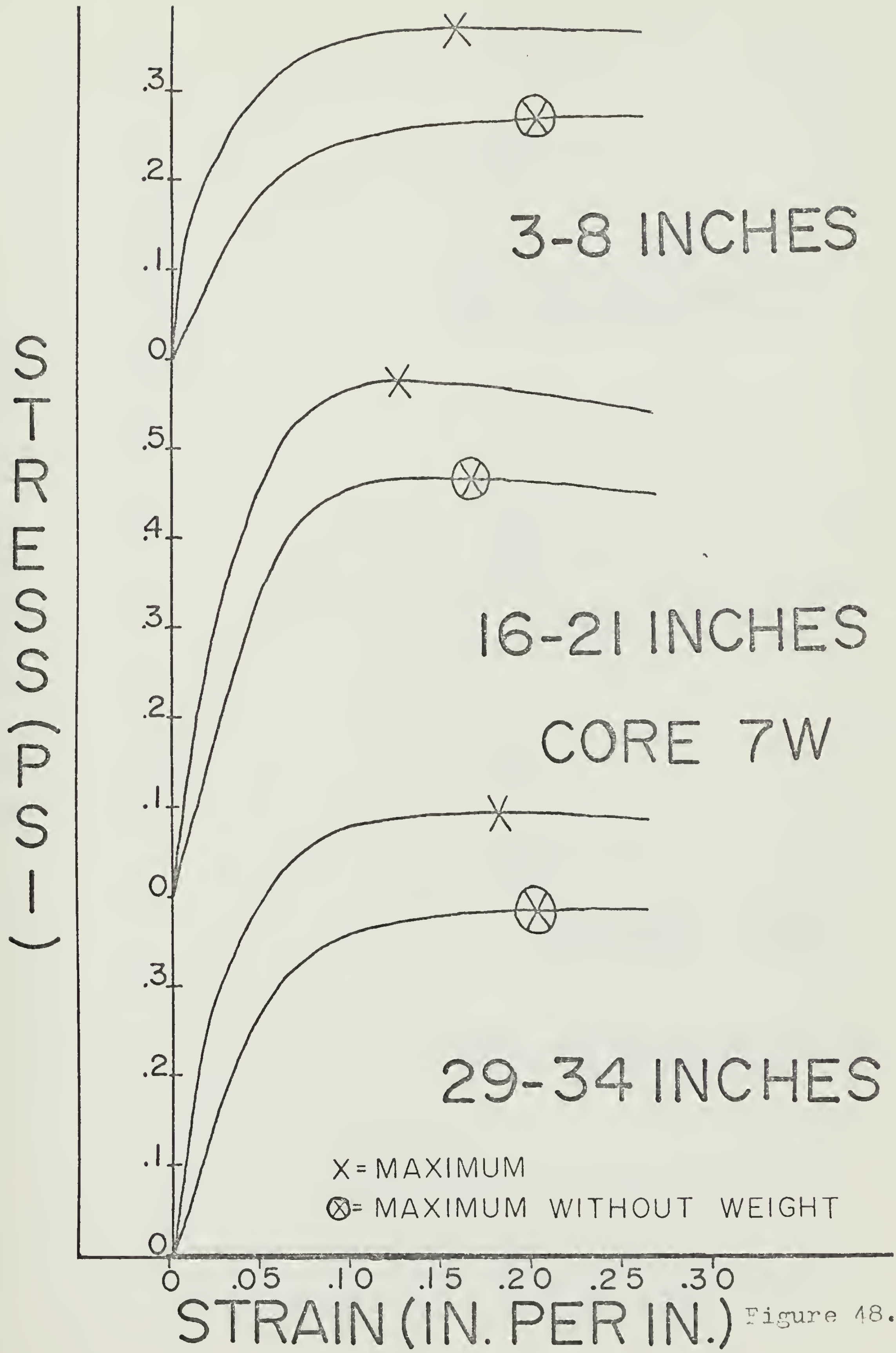

3-8 INCHES
16-21 INCHES
CORE 7W
29-34 INCHES
X = MAXIMUM
⊗= MAXIMUM WITHOUT WEIGHT
STRESS (PSI)
STRAIN (IN. PER IN.)
0
.05
.10
.15
.20
.25
.30
.1
.2
.3
.4
.5

Figure 48.

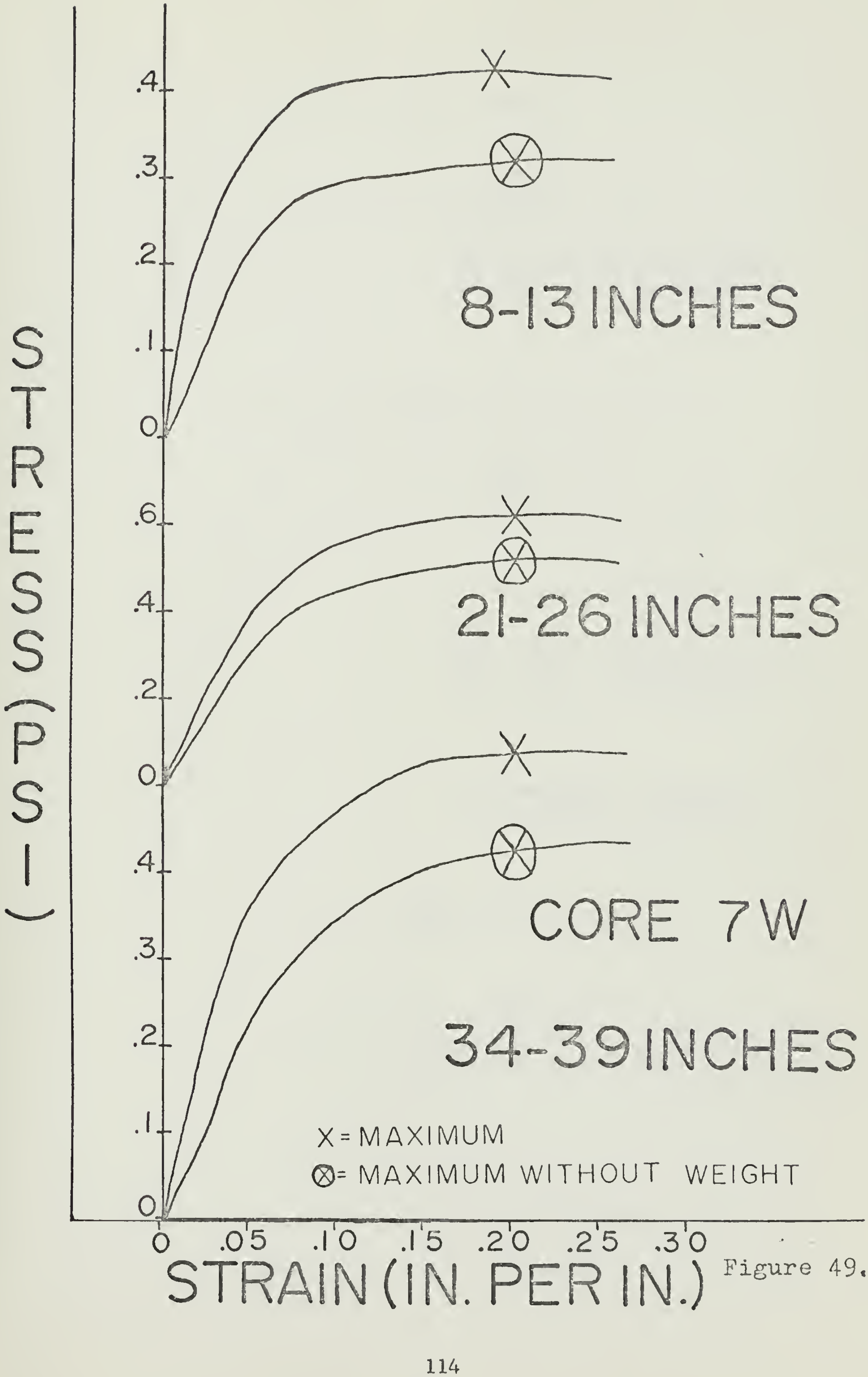
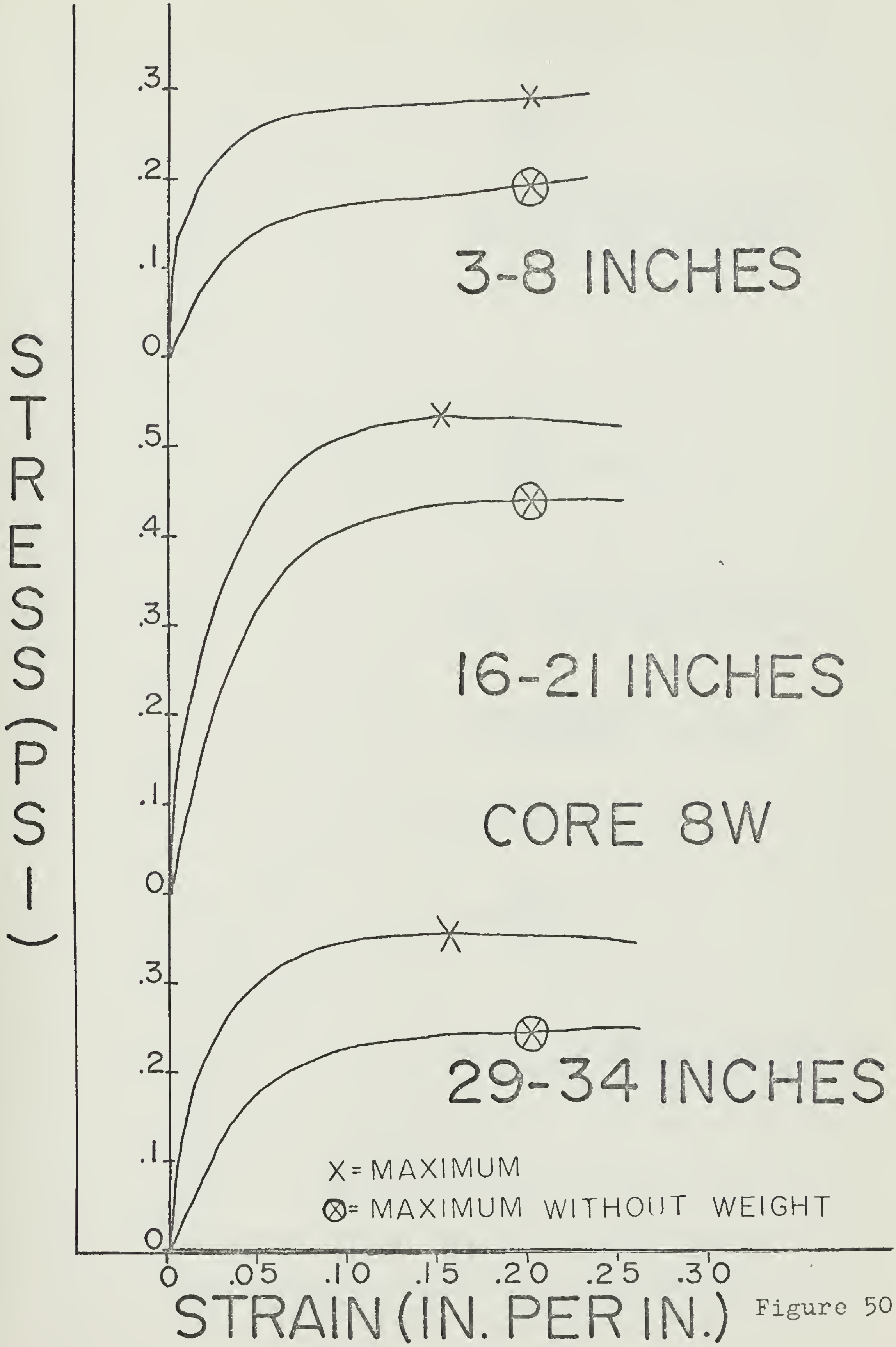

STRESS (PSI)
.4
.3
.2
.1
0
.6
.4
.2
0
.4
.3
.2
.1
0
8-13 INCHES
21-26 INCHES
CORE 7W
34-39 INCHES
X = MAXIMUM
⊗= MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 49.



STRESS (PSI)
.3
.2
.1
0
.5
.4
.3
.2
.1
0
.3
.2
.1
0
3-8 INCHES
16-21 INCHES
CORE 8W
29-34 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 50.

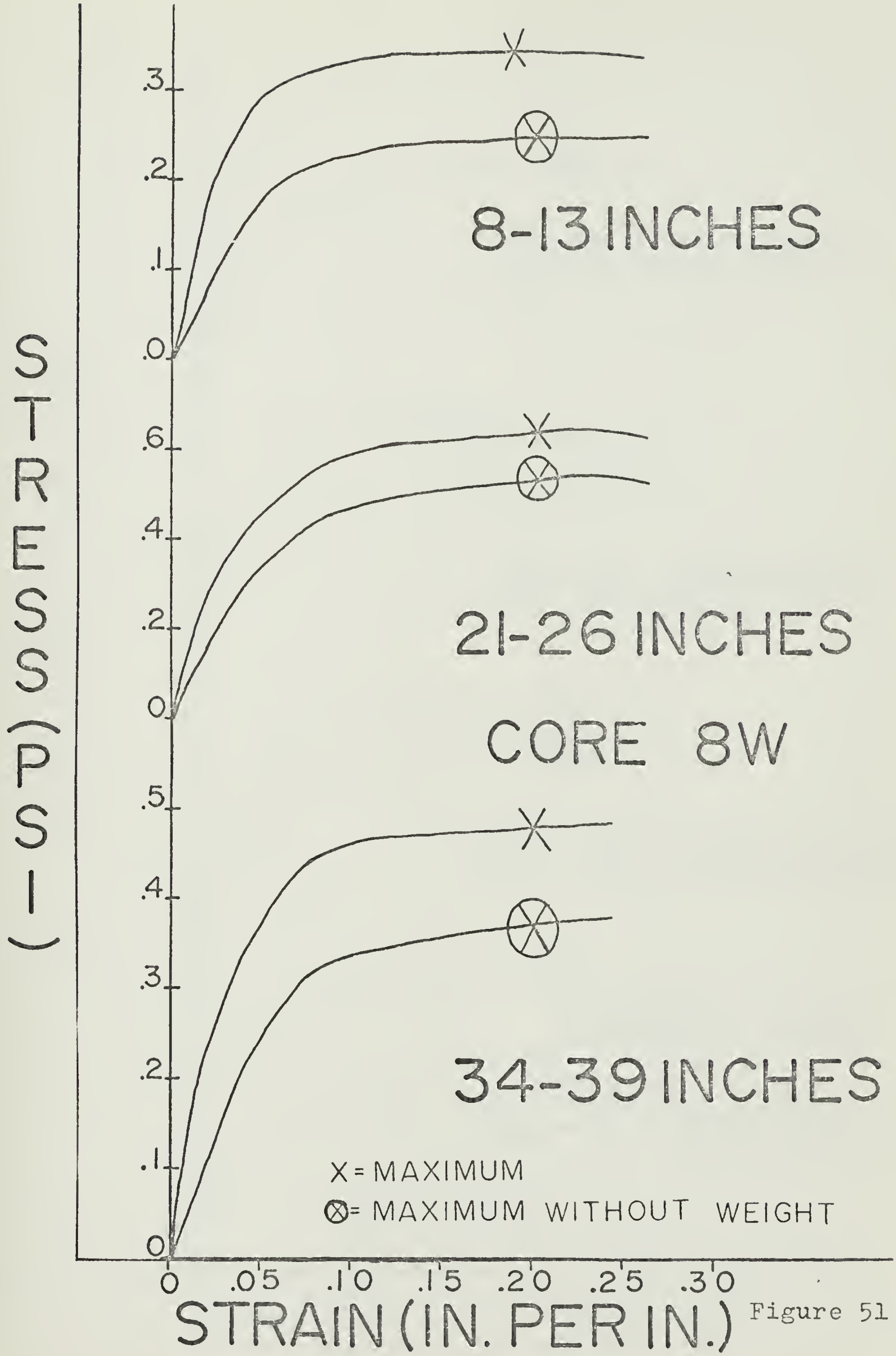

STRESS (PSI)
.3
.2
.1
.0
8-13 INCHES
.6
.4
.2
0
21-26 INCHES
CORE 8W
.5
.4
.3
.2
.1
0
34-39 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0 .05 .10 .15 .20 .25 .30
STRAIN (IN. PER IN.)

Figure 51.

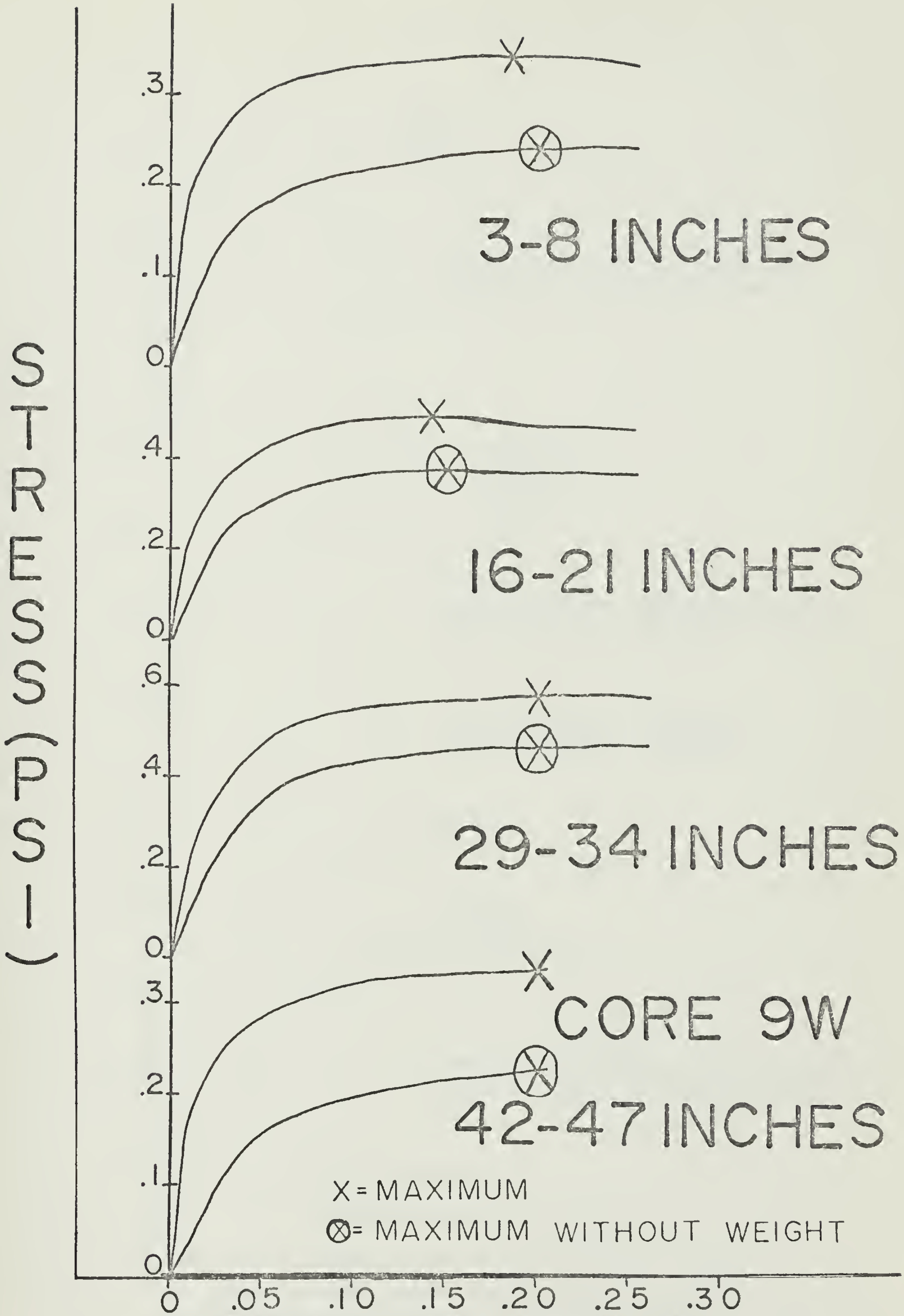

STRESS (PSI)
.3
.2
.1
0
.4
.2
0
.6
.4
.2
0
.3
.2
.1
0
3-8 INCHES
16-21 INCHES
29-34 INCHES
CORE 9W
42-47 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 52.

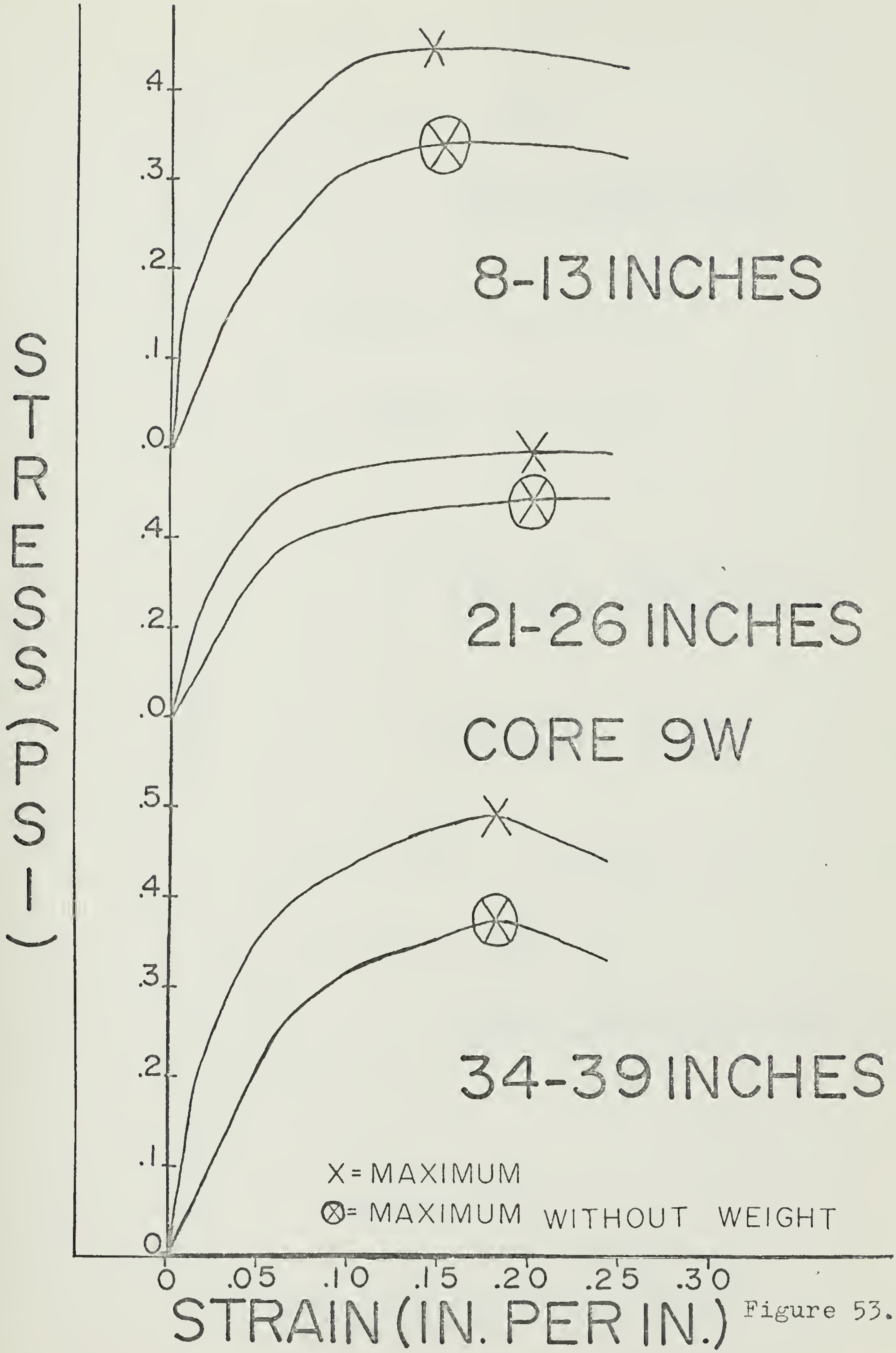

STRESS (PSI)
.4
.3
.2
.1
.0
.4
.2
.0
.5
.4
.3
.2
.1
0
8-13 INCHES
21-26 INCHES
CORE 9W
34-39 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 53.

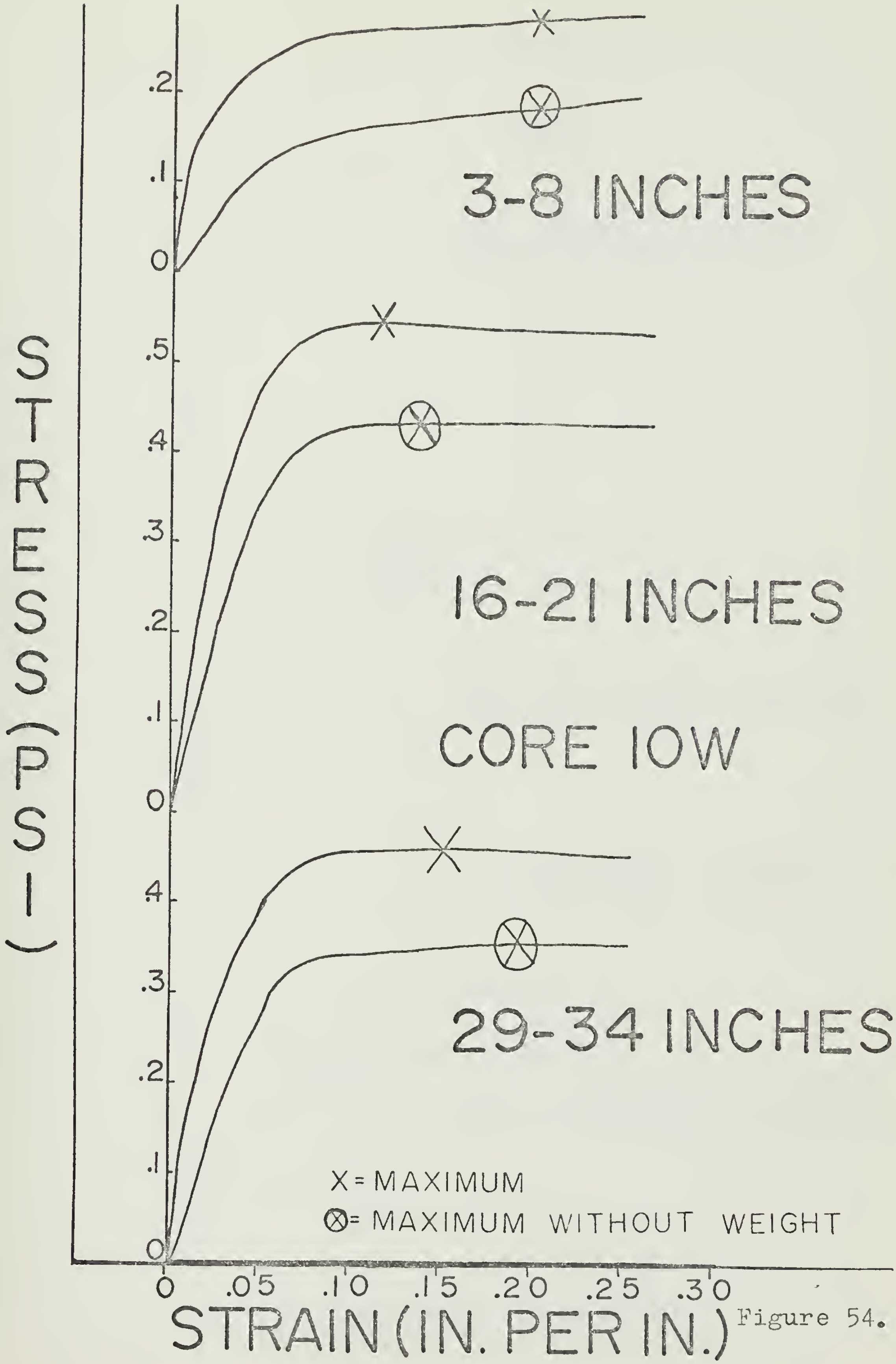

STRESS (PSI)
.2
.1
0
3-8 INCHES
.5
.4
.3
.2
.1
0
16-21 INCHES
CORE 10W
.4
.3
.2
.1
0
29-34 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 54.

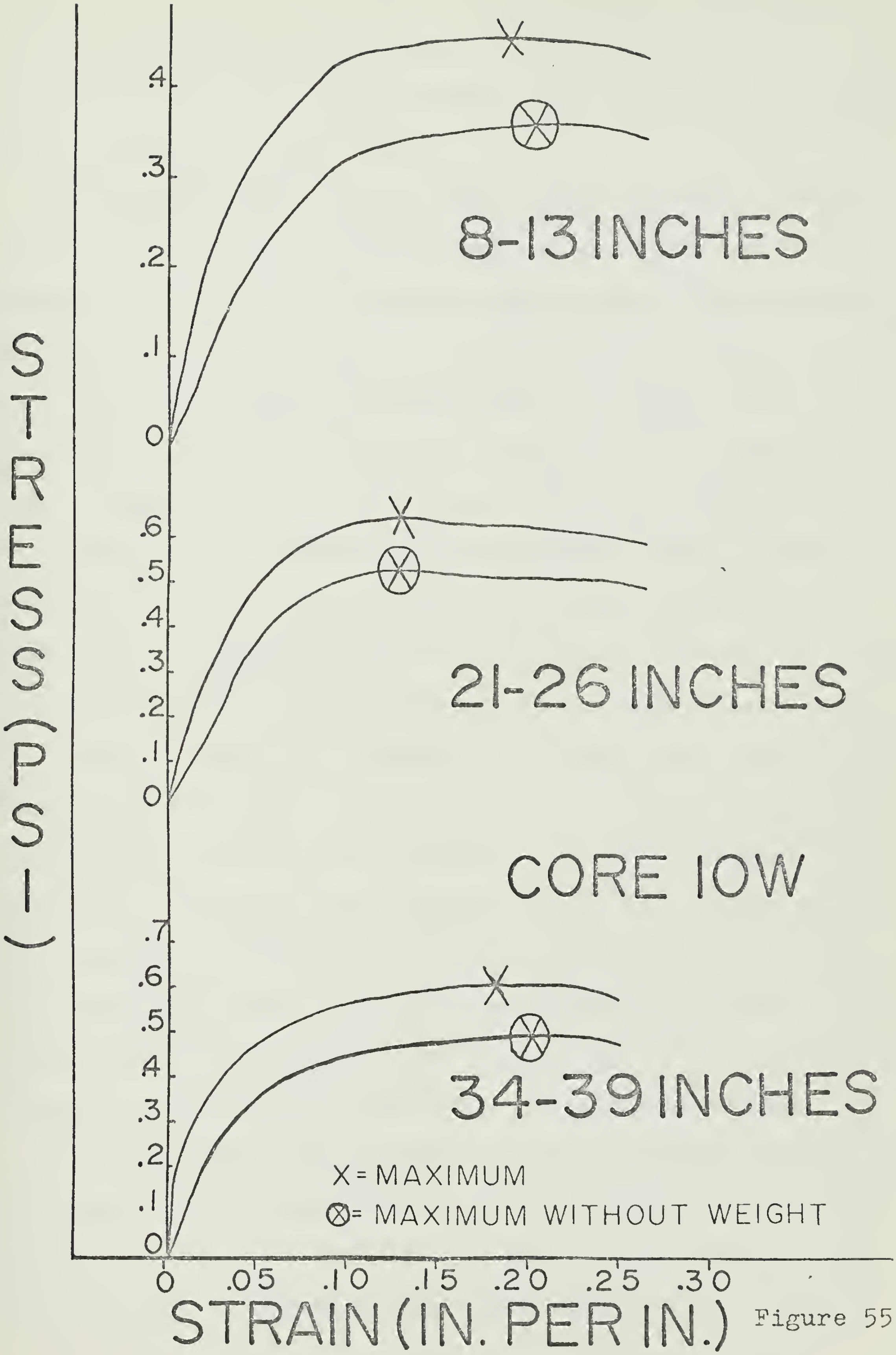

STRESS (PSI)
.4
.3
.2
.1
0
8-13 INCHES
.6
.5
.4
.3
.2
.1
0
21-26 INCHES
CORE 10W
.7
.6
.5
.4
.3
.2
.1
0
34-39 INCHES
X = MAXIMUM
⊗ = MAXIMUM WITHOUT WEIGHT
0
.05
.10
.15
.20
.25
.30
STRAIN (IN. PER IN.)

Figure 55.

occurred on the 3- to 8-inch sample for Core 1W, and is perhaps invalid. The curve for the 34- to 39-inch sample for Core 9W dropped off at a point beyond 20 percent strain. The flattening of the remaining curves begins in the vicinity of the linear point.

A comparison was made for each sample between the linear strength with and without sample weight and the maximum strength on the faired stress-strain curve. The 20 percent strength with and without sample weight was also compared to the maximum faired curve strength. The results are given in percent in Table XII and Table XIII. An example of these results is the 55-60 inch section of Core 5W. In this section the ratio of the linear strength which includes the sample weight to the maximum faired curve strength is 99.2 percent. Without the sample weight included, this ratio is 96.4 percent. The ratio of the 20 percent strength with the sample weight to the maximum faired curve strength is 99.4 percent. This ratio is 100.0 percent neglecting sample weight. Without including Core 1W, 70 sediment samples were analyzed. Of the four shear strength comparisons made for each sample (a total of 280) only 13 differed by greater than 10 percent from the faired curve strength. Only 42 were outside of a five percent band. Fifty-four shear strength values exactly equaled the faired curve strength. Of importance is the fact that there was no preference as to whether the linear or the 20 percent strength more closely approximated the faired curve strength. The shear strength at the linear point was therefore considered to be the actual sediment shear strength.

A primary design goal of the NPS unconfined compression testing machine was inclusion of the sample weight as part of the measured load. Sample weight was considered as an integrating type load, with the maximum load due to the weight of the sample itself being at the bottom of the test

TABLE XII

CORE SHEAR STRENGTH COMPARISON TABLE

TOP ROW FOR A SAMPLE: RATIO OF LINEAR STRENGTH/FAIRED CURVE STRENGTH IN %
BOTTOM ROW FOR A SAMPLE: RATIO OF 20% STRENGTH/FAIRED CURVE STRENGTH IN %

DEPTH (INCHES)	CORE 1 W WITH SAMPLE WEIGHT	CORE 1 W W/O SAMPLE WEIGHT	CORE 2 W WITH SAMPLE WEIGHT	CORE 2 W W/O SAMPLE WEIGHT	CORE 3 W WITH SAMPLE WEIGHT	CORE 3 W W/O SAMPLE WEIGHT	CORE 4 W WITH SAMPLE WEIGHT	CORE 4 W W/O SAMPLE WEIGHT	CORE 5 W WITH SAMPLE WEIGHT	CORE 5 W W/O SAMPLE WEIGHT
3 - 8	40.1	23.3	100.0	100.0	96.6	92.0	98.5	93.7	100.0	97.4
	48.0	36.7	99.6	100.0	99.2	100.0	99.6	100.0	97.7	99.4
8 - 13	83.3	77.1	101.0	100.0	94.3	91.2	100.0	100.0	98.0	94.0
	100.0	100.0	95.5	94.7	100.5	101.5	99.4	102.9	97.4	97.0
16 - 21	91.5	89.3	92.4	79.9	99.5	97.5	100.0	99.1	99.8	97.9
	100.0	100.0	100.0	100.0	99.6	100.2	99.3	100.0	100.0	100.0
21 - 26	78.4	74.4	99.9	98.5	100.0	100.0	99.6	97.5	98.9	96.9
	97.4	96.9	99.1	99.4	89.1	89.8	104.4	104.8	105.7	107.5
29 - 34	92.7	86.1	100.0	99.9	98.3	95.1	99.7	97.8	100.0	100.0
	98.5	95.9	98.5	99.1	100.4	100.7	99.9	100.0	99.2	100.0
34 - 39	84.7	80.5	97.6	97.4	93.0	90.9	96.7	92.6	97.7	97.9
	98.1	98.4	97.7	99.3	99.8	102.5	102.5	102.6	98.9	100.2
42 - 47	93.8	92.5	100.2	98.4	94.4	89.5	95.6	91.4	99.3	96.6
	100.0	100.0	99.0	99.8	100.0	100.0	100.4	100.2	99.7	99.8
47 - 52	92.9	90.5	96.6	92.9	97.0	94.8	97.7	97.0	98.2	95.1
	100.0	100.0	101.8	100.2	89.4	87.3	97.7	99.0	99.1	100.9
55 - 60			98.3	96.7	100.0	98.7			99.2	96.4
			100.0	99.9	99.3	99.8			99.4	100.0
60 - 65			101.4	89.5	98.5	96.1			97.2	95.8
			100.7	95.9	98.3	97.8			99.4	100.2

TABLE XIII

CORE SHEAR STRENGTH COMPARISON TABLE

TOP ROW FOR A SAMPLE: RATIO OF LINEAR STRENGTH/FAIRED CURVE STRENGTH IN %
BOTTOM ROW FOR A SAMPLE: RATIO OF 20% STRENGTH/FAIRED CURVE STRENGTH IN %

DEPTH (INCHES)	CORE 6 W WITH SAMPLE WEIGHT	CORE 6 W W/O SAMPLE WEIGHT	CORE 7 W WITH SAMPLE WEIGHT	CORE 7 W W/O SAMPLE WEIGHT	CORE 8 W WITH SAMPLE WEIGHT	CORE 8 W W/O SAMPLE WEIGHT	CORE 9 W WITH SAMPLE WEIGHT	CORE 9 W W/O SAMPLE WEIGHT	CORE 10 W WITH SAMPLE WEIGHT	CORE 10 W W/O SAMPLE WEIGHT
3 - 8	96.2	91.1	99.5	96.3	95.2	85.6	99.4	97.1	93.3	82.8
	97.1	101.5	99.5	100.0	100.0	100.0	100.0	100.4	100.0	100.0
8 - 13	97.5	92.8	96.5	92.5	98.3	93.3	96.0	93.5	99.8	97.8
	99.7	101.1	101.2	102.5	100.3	100.0	100.0	101.8	99.8	99.2
16 - 21	98.3	92.9	100.2	100.1	100.0	98.9	100.0	100.0	101.3	100.5
	100.0	100.0	97.7	98.9	100.0	100.0	97.3	98.4	98.0	99.5
21 - 26	98.4	97.6	94.5	88.9	96.4	94.2	95.3	92.7	98.3	97.5
	100.6	102.0	98.7	96.4	100.0	100.0	99.7	100.0	98.9	100.8
29 - 34	100.1	99.1	99.6	97.4	99.2	95.6	98.8	96.8	100.0	98.6
	99.6	100.0	99.8	100.0	99.7	100.0	100.0	100.0	99.6	100.0
34 - 39	94.7	92.7	94.4	91.8	88.3	80.4	96.4	89.5	95.9	94.7
	99.4	99.3	98.9	99.3	99.8	99.5	97.7	94.4	97.0	98.0
42 - 47	98.7	96.7					94.4	85.5		
	100.2	100.0					100.0	100.0		
47 - 52										
55 - 66										
60 - 65										

section. Since the samples tested each weighed approximately one pound, this weight load ranged from 10 to almost 50 percent of the failure load, with an average of about 20 percent. This is considered significant.

To verify the importance of sample weight as part of the failure load, each sample was inspected to determine where failure occurred. The results are tabulated in Table XIV. Examination of this table indicates that of the 70 samples tested (excluding Core 1W) seven samples failed at the top while 52 samples failed at the bottom. The remaining 11 samples failed at both the top and the bottom. There were no failures through the center portion of the samples. Although variations existed, most cores increased slightly in shear strength with depth of core as shown by Figure 56 through Figure 65. This implies that the bottom part of a sample should have been very slightly stronger than the top, and the failure plane should therefore have originated at the top. Since this was generally not the case, the sample weight appears to have been a sufficient added load to cause failure at the bottom of the sample.

The angle of the failure plane with respect to the horizontal is also tabulated in Table XIV for each sample. Typical failed samples are shown in Figure 66. With the exception of two samples, all 78 failed at an angle of 60 $\pm$ 4 degrees. Fifty of the samples failed at exactly 60 degrees. This indicates a friction angle ϕ of 30 degrees for most samples since

$$\theta = 45° + \frac{\phi}{2}$$

where

θ = Angle of failure with respect to the horizontal.

This is considered of appreciable consequence in that the friction angle, as noted previously, has always been assumed equal to zero for marine sediments. This assumption apparently is not valid and considerable solid

TABLE XIV

CORE FAILURE PLANE SUMMARY TABLE

TOP ROW FOR A SAMPLE: AREA OF SAMPLE WHERE FAILURE OCCURRED
BOTTOM ROW FOR A SAMPLE: ANGLE OF FAILURE PLANE WITH THE HORIZONTAL

DEPTH (INCHES)	CORE 1 W	CORE 2 W	CORE 3 W	CORE 4 W	CORE 5 W	CORE 6 W	CORE 7 W	CORE 8 W	CORE 9 W	CORE 10 W
3 - 8	None	Top	Bottom	Both	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom
	None	60	60	60	60	60	60	60	70	60
8 - 13	Top	Bottom	Bottom	Bottom	Bottom	Bottom	Top	Top	Top	Top
	60	60	60	60	60	63	60	60	60	60
16 - 21	Bottom	Bottom	Both	Bottom	Both	Bottom	Bottom	Both	Bottom	Both
	60	61	60	60	60	60	58	60	60	60
21 - 26	Top	Bottom	Bottom	Bottom	Bottom	Both	Bottom	Bottom	Bottom	Bottom
	60	57	60	58	60	60	60	61	65	59
29 - 34	Bottom	Bottom	Bottom	Bottom	Both	Bottom	Both	Both	Both	Bottom
	60	60	58	64	60	53	60	60	60	60
34 - 39	Top	Bottom	Bottom	Bottom	Bottom	Bottom	Both	Bottom	Top	Bottom
	60	63	62	60	60	60	60	60	60	60
42 - 47	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom			Bottom	
	60	58	58	56	58	60			60	
47 - 52	Bottom	Bottom	Bottom	Bottom	Bottom					
	58	64	58	60	58					
55 - 60		Bottom	Bottom		Top					
		55	61		64					
60 - 65		Bottom	Bottom		Bottom					
		64	57		60					

CORE NO: IW

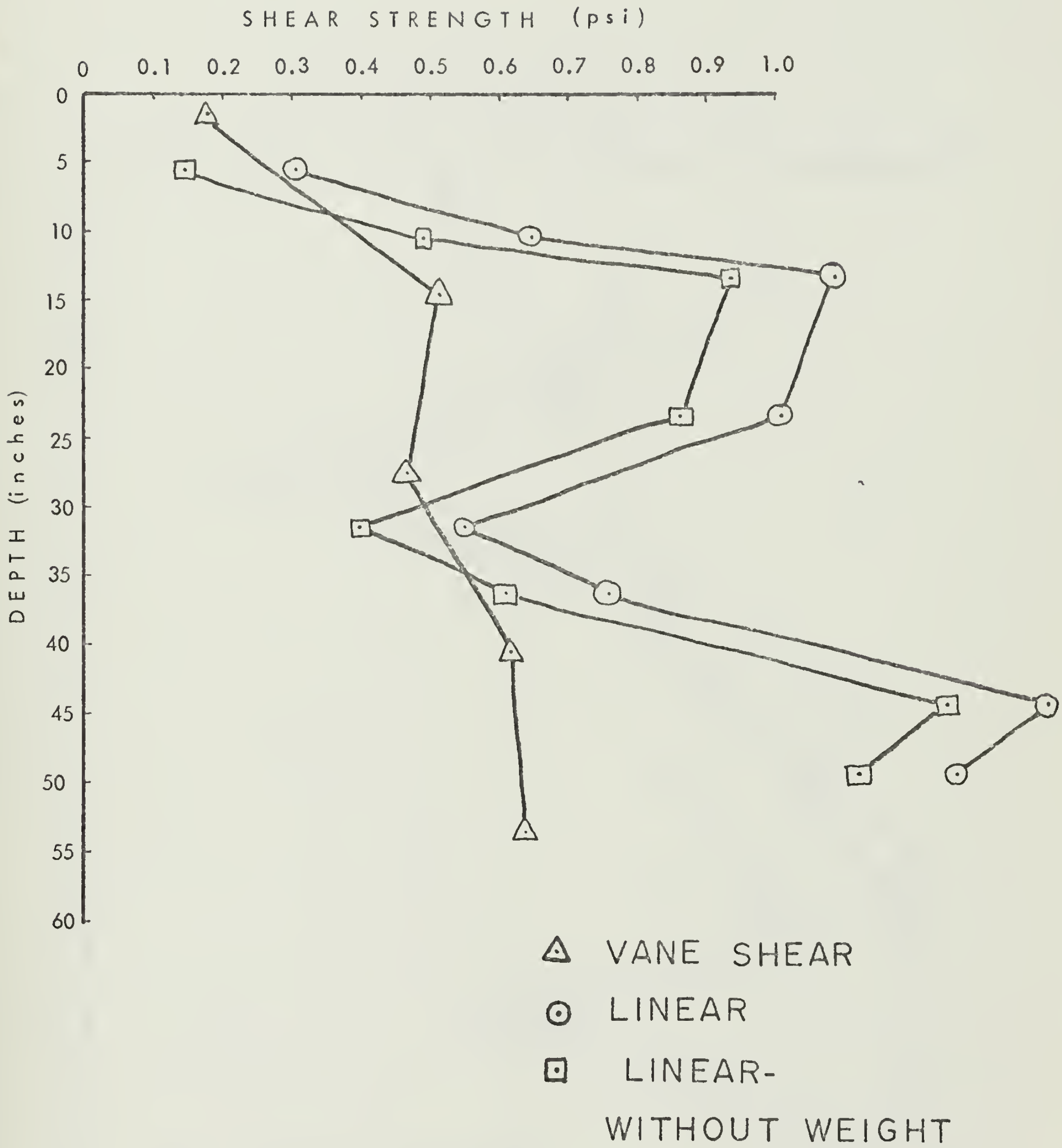


Figure 56.

CORE NO: 2W

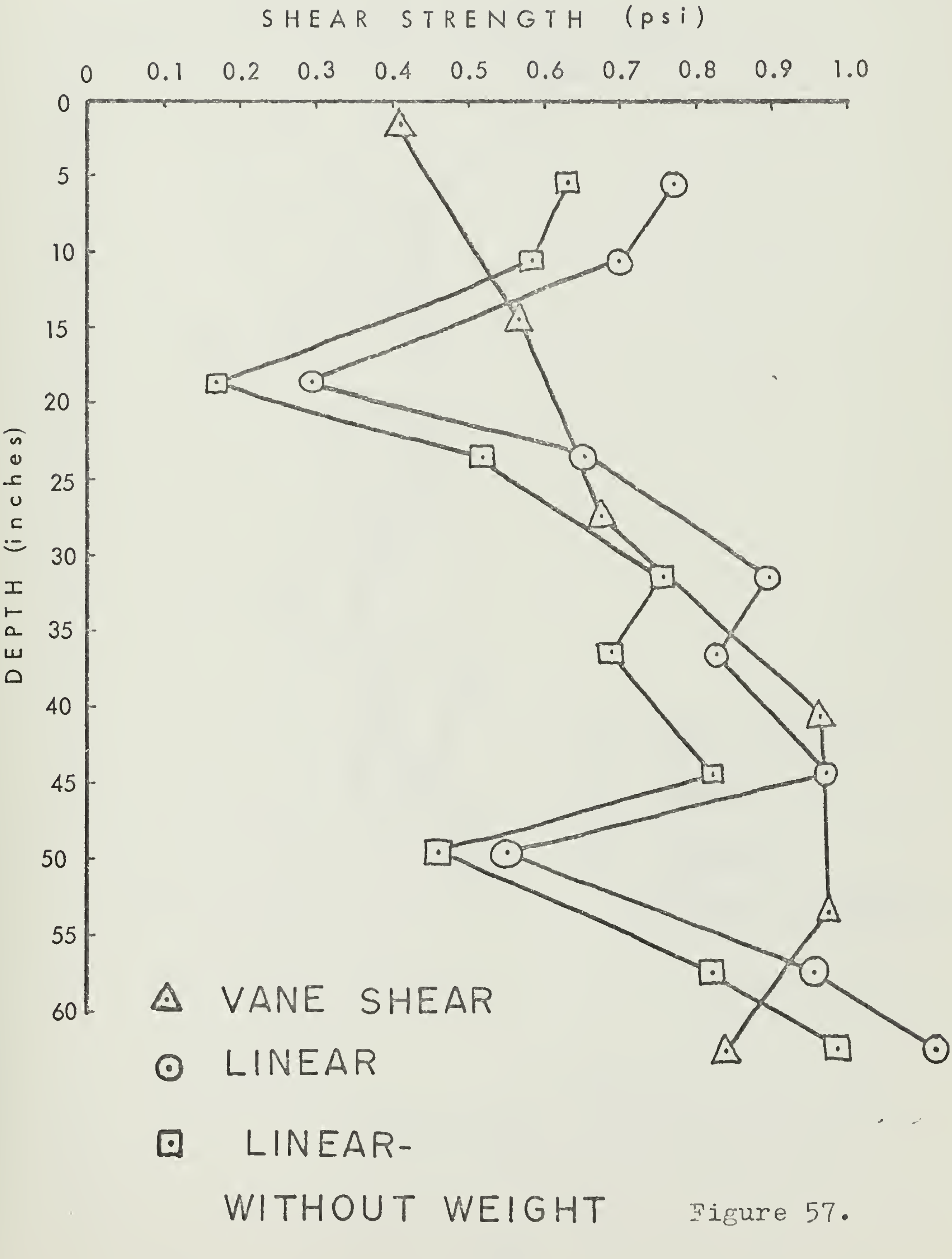


Figure 57.

CORE NO: 3W

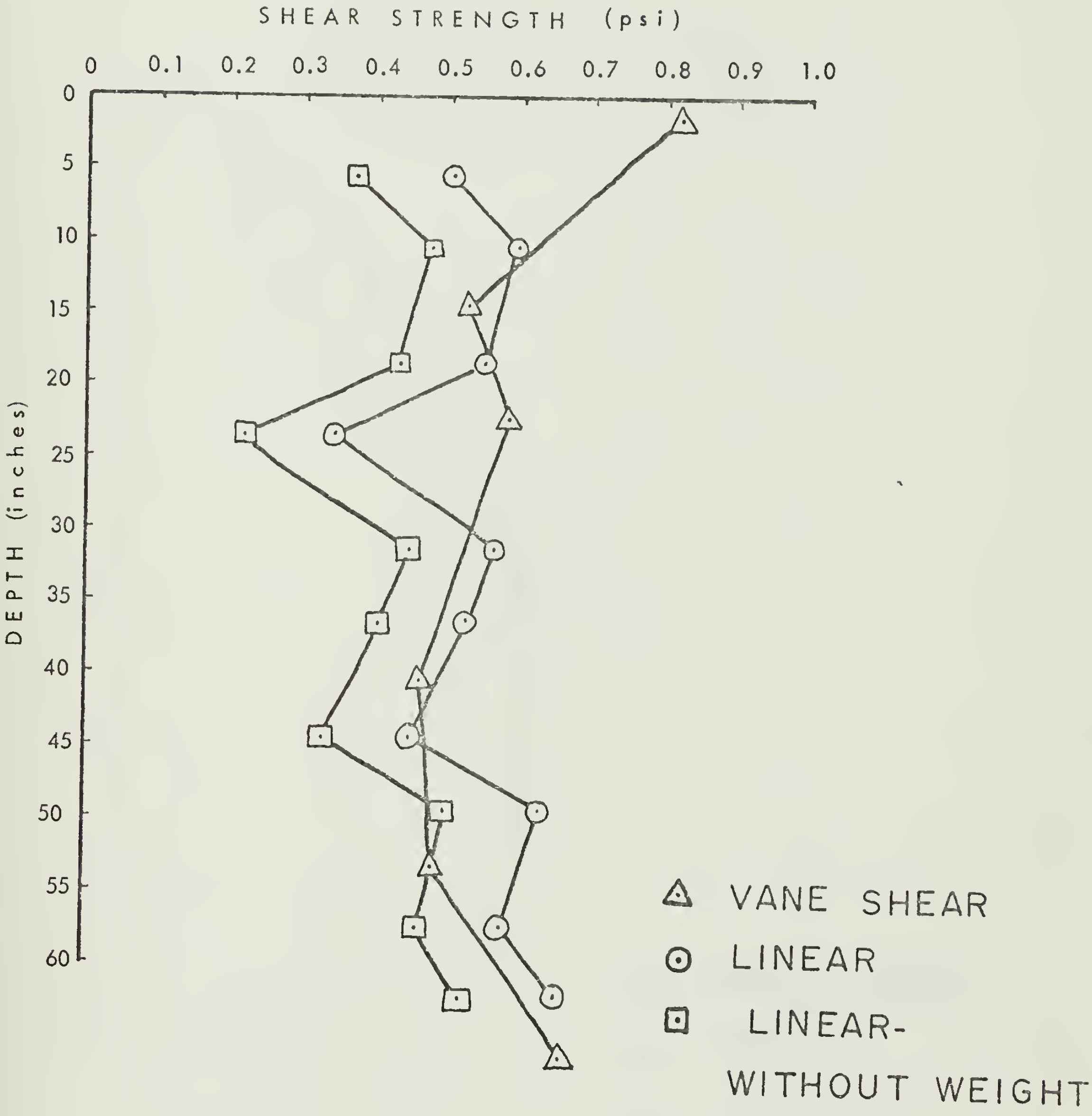


Figure 58.

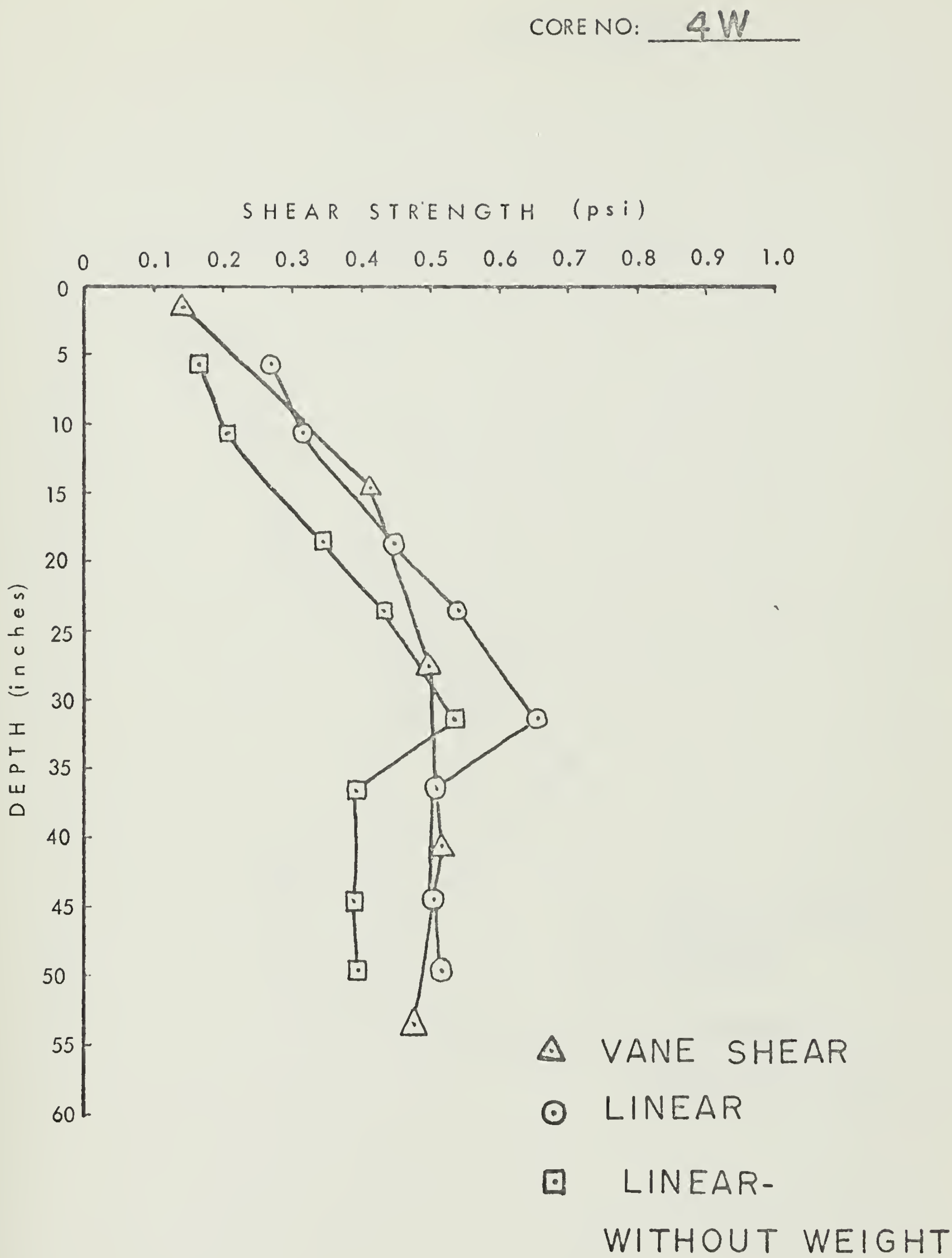

CORE NO: 4W
SHEAR STRENGTH (psi)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
DEPTH (inches)
0 5 10 15 20 25 30 35 40 45 50 55 60
VANE SHEAR
LINEAR
LINEAR-
WITHOUT WEIGHT

Figure 59.

CORE NO: 5 W

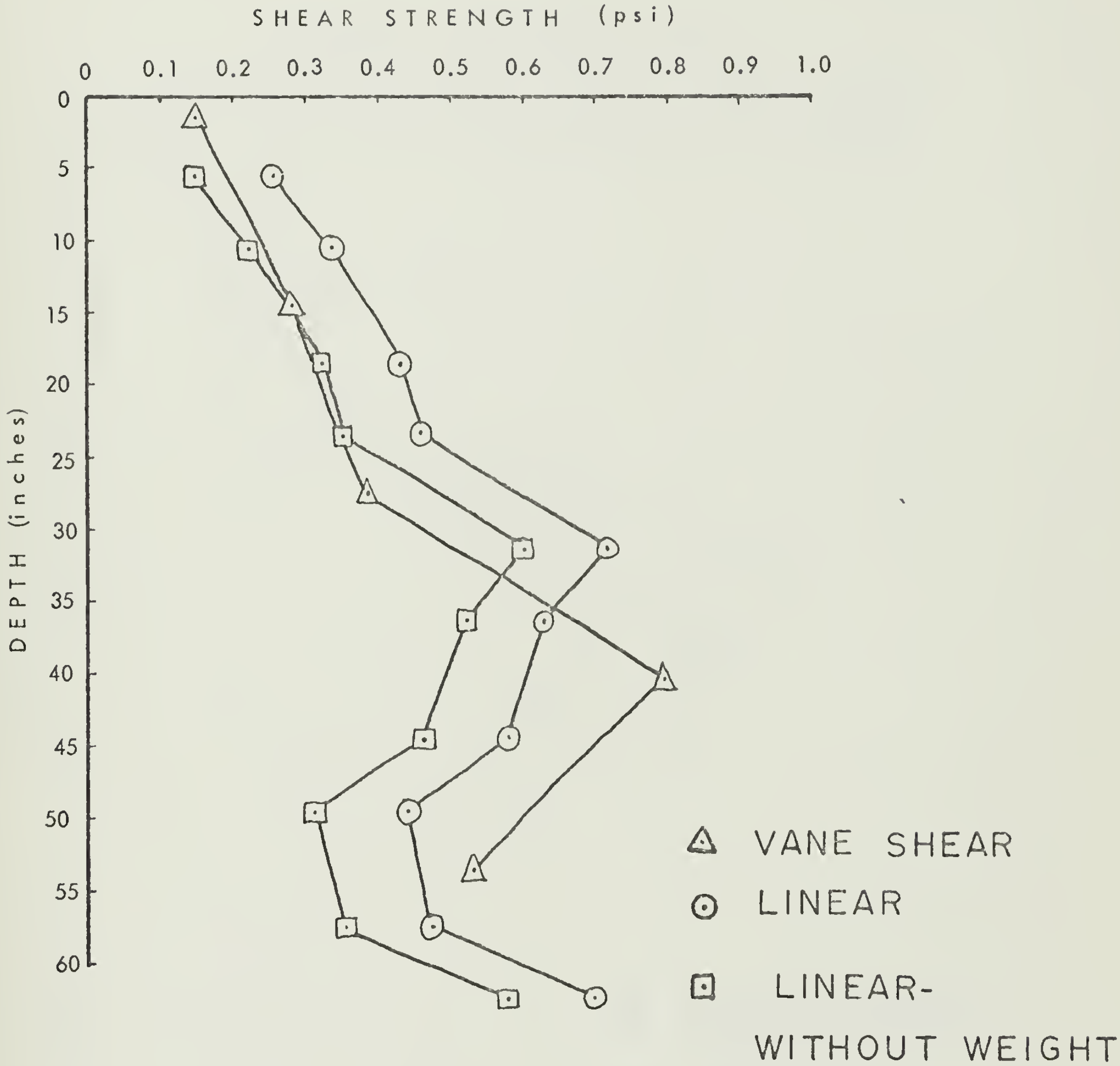


Figure 60.

CORE NO: 6W

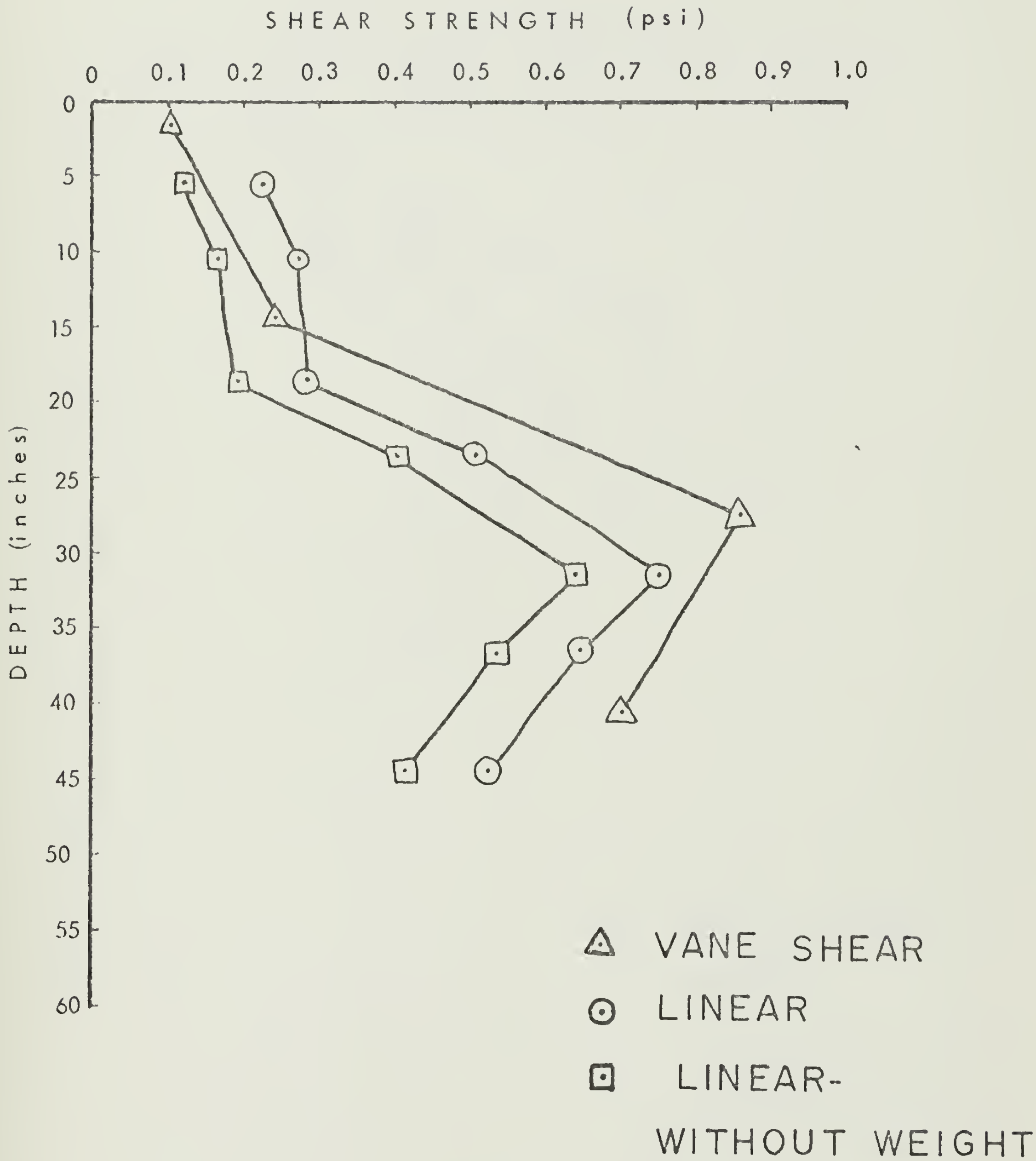


Figure 61.

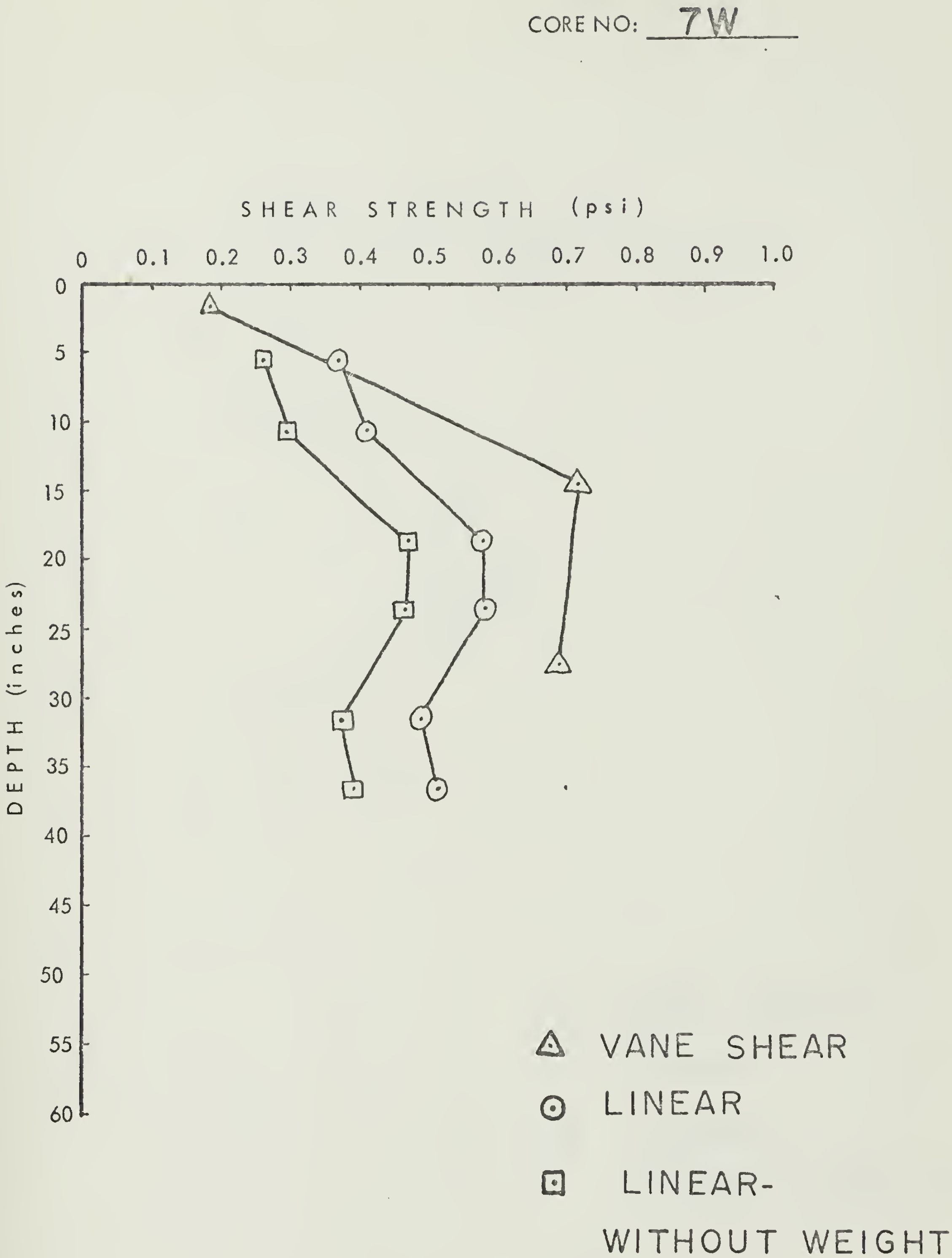

CORE NO: 7W
SHEAR STRENGTH (psi)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
DEPTH (inches)
0
5
10
15
20
25
30
35
40
45
50
55
60
VANE SHEAR
LINEAR
LINEAR-
WITHOUT WEIGHT

Figure 62.

CORE NO: 8 W

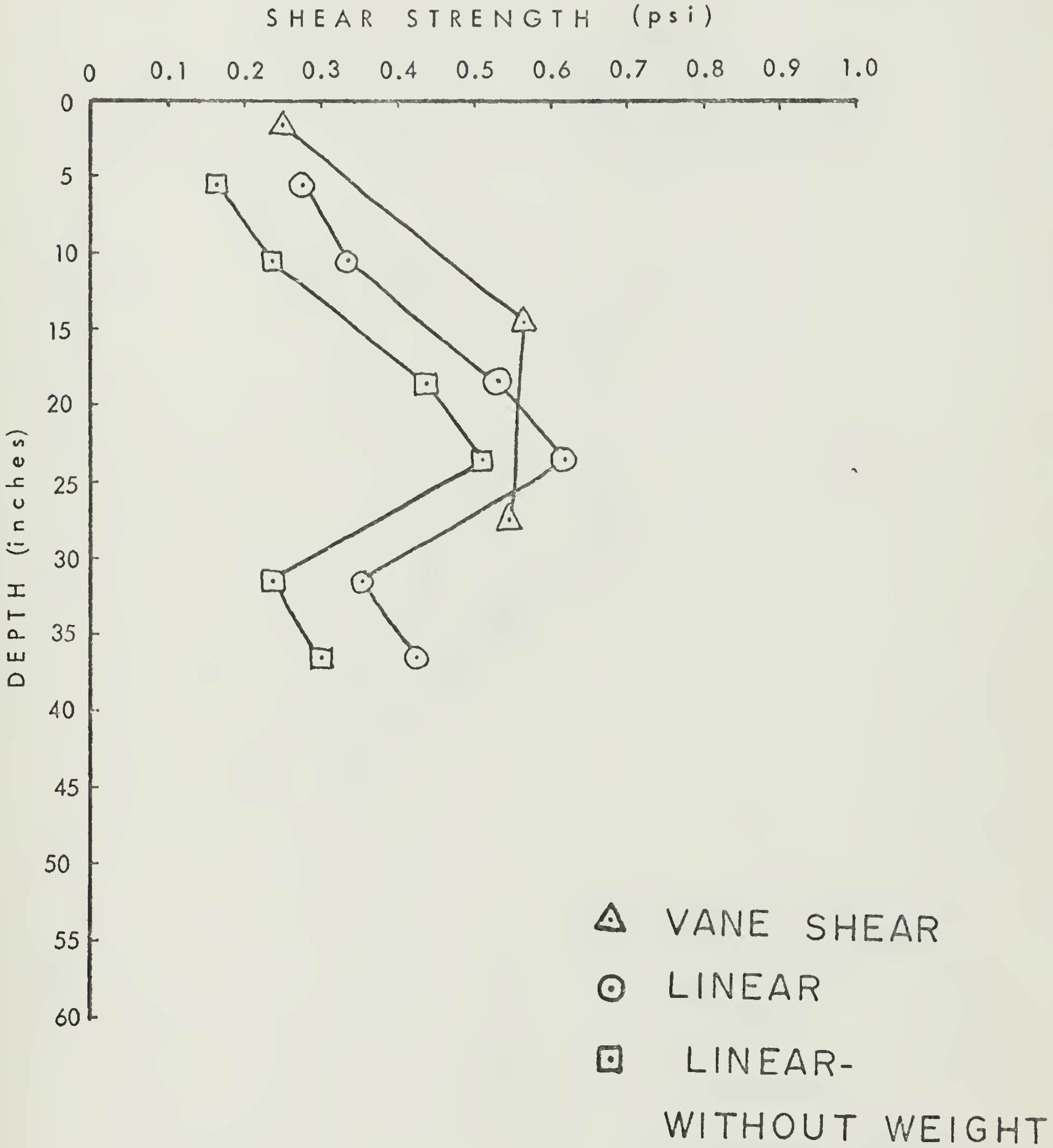


Figure 63.

CORE NO: 9W

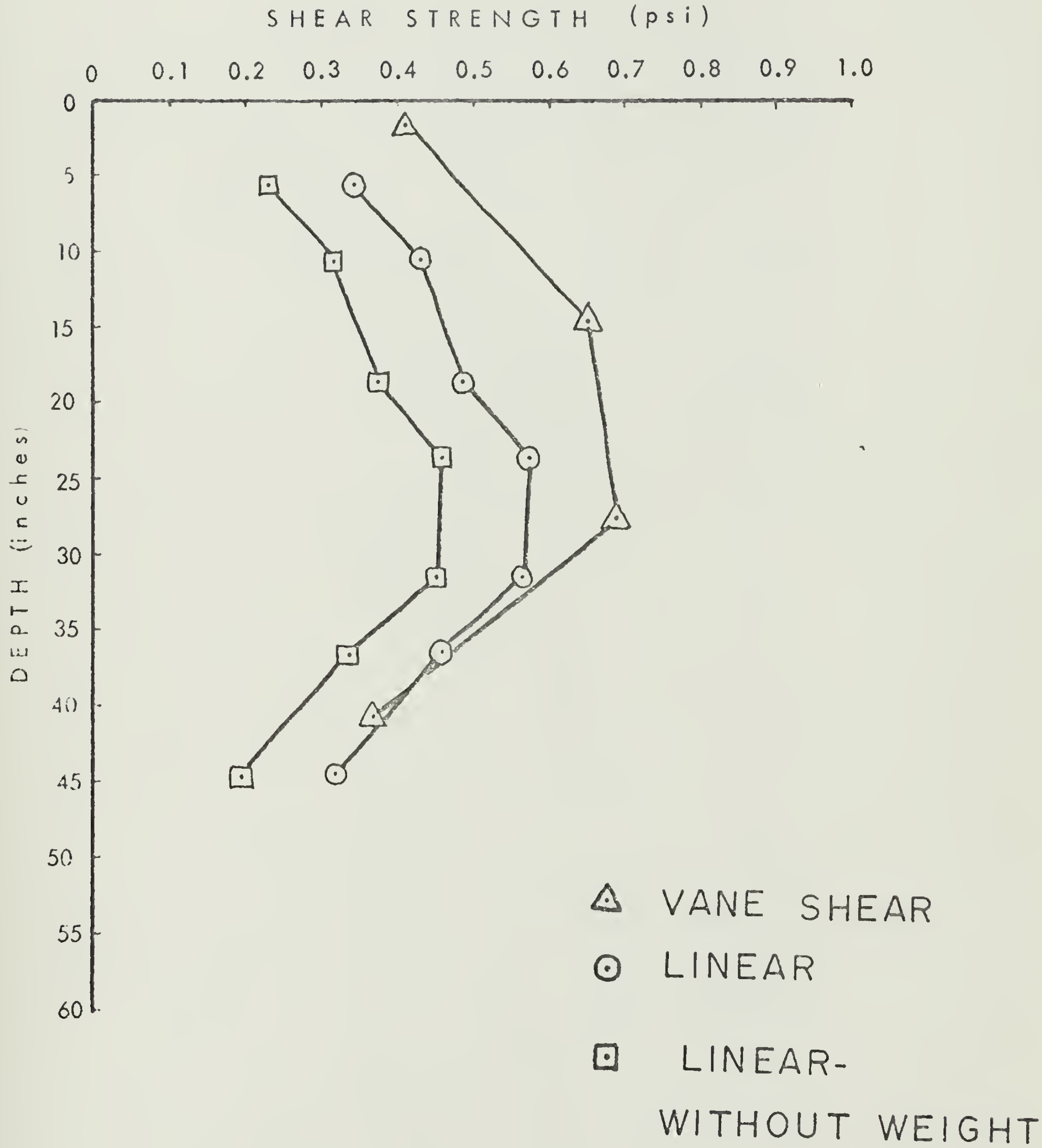


Figure 64.

CORE NO: 10W

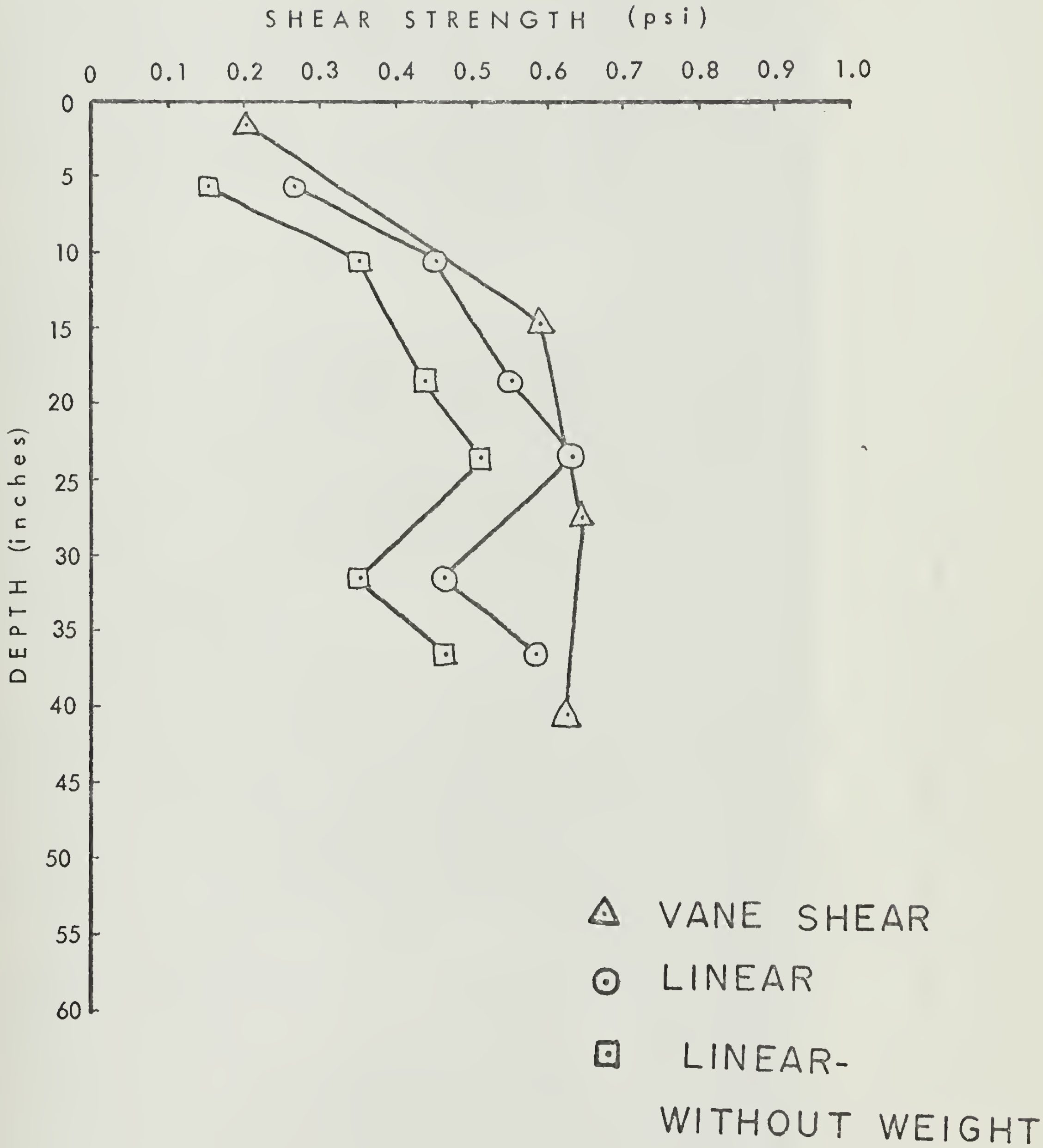


Figure 65.

Figure 66. Typical Failed Samples

friction does appear to exist. If the friction angle is 30 degrees, then the utilization of sediment shear strength values would have to take this ϕ-angle into account for all purposes. For example, it would appreciably affect present methods of computing the bearing capacity of sea floor materials. The results of this investigation indicate that it is mandatory that triaxial tests be conducted on marine sediments to confirm the existence of this solid friction and to give comparison data for the unconfined and vane shear methods of testing.

Figure 56 through Figure 65 show the linear strength, linear strength without weight, and vane shear strength plotted against core depth. With the exception of Core 1W and two low peaks in the linear strength curves of Core 2W, all curves are remarkably similar in shape. The vane shear strength curves compare more favorably with the linear strength curves which include sample weight than to those without sample weight. In Cores 6W through 10W the vane shear curves were slightly higher in value than the linear strength curves. Perhaps this is due to slight disturbance on removing the samples from the core liners. The Core 3W and Core 4W curves are almost identical.

The agreement between the unconfined compression shear strength curves and the vane shear strength curves is considered important. It shows that both methods are accurate enough to concur in measuring the variations in cohesion with sample depth. Additionally, confidence is gained in the values of shear strength obtained when using a vane shear device because they compare so closely to those measured using the classical unconfined compression test.

VI. CONCLUSIONS

The sediment shear strength computed from the linear point of the load - sample height curve as recorded by the NPS unconfined compression testing machine represents the actual sediment strength as measured by this test device.

Friction losses and load changes due to incremental sample shear could represent a large fraction of the failure load of low strength marine sediments. To account for these variations, unconfined compression testing apparatus that test in the stress-controlled mode should measure the actual load being applied to the sample.

The strain-controlled mode of the NPS unconfined compression testing machine produces a smooth load - sample height curve. An accurate linear strength can easily be computed from this curve. This mode of testing should be used whenever possible.

Sample weight can represent a large fraction of the total load to cause failure on low strength marine sediments. This should be considered in the calculations for sediment shear strength.

The friction angle for the marine sediments tested on the NPS unconfined compression testing machine averaged 30 degrees. Calculations for sediment shear strength have heretofore assumed that friction angle was zero. This aspect appears to require considerable further study.

Sediment shear strengths obtained from the NPS unconfined compression testing machine are in close agreement with those obtained using the NPS vane shear apparatus, and hence confirm the usefulness of vane shear equipment for measurements of cohesion.

VII. RECOMMENDATIONS FOR FURTHER RESEARCH

The following areas associated with the NPS unconfined compression testing machine are recommended for additional research:

1. Determine quantitatively the effects of varying the rate of strain, sample height, and load increments.

2. Develop a device that removes the sediment sample from the core liner in the same direction as the sample entered the liner as a means of further reducing sample disturbance.

3. Closely examine the previously widely adopted concept that the Ø-angle for deep sea sediments is close to zero.

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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3 REPORT TITLE

An Unconfined Compression Testing Machine for Marine Sediments

4 DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; September 1970

5. AUTHOR(S) (First name, middle initial, last name)

Richard Karl Westfahl

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1970	141	18

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10 DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

The two most common laboratory test methods used for measuring the undisturbed or original shear strength of marine sediments are the vane shear test and the unconfined compression test. The application of the load in the unconfined compression test is accomplished either in a strain-controlled or a stress-controlled manner. An unconfined compression testing machine was constructed to allow application of the load by either the strain-controlled or stress-controlled method, and it was specifically designed to accurately test marine sediments having relatively low values of shear strength. A unique feature of the apparatus is that it provides a continuous plot of displacement versus load throughout the test procedure. Tests for shear strength in the two load application modes were conducted on gravity cores taken on the continental slope between San Francisco and Monterey. Results of the tests compared favorable with each other, as well as with values secured from vane shear testing. The tests suggest that these particular sediments have friction angles approximating 30 degrees.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

UNCLASSIFIED

Security Classification

A-31408

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Compression Testing						
Cores						
Data						
Deep Sea Cores						
Deep Sea Sediments						
Engineering Properties of Marine Sediments						
Friction Angle						
Marine Sediments						
Sediment Engineering Properties						
Sediment Cores						
Sediments						
Shear Strength						
Unconfined Compression Test						
Vane Shear Strength						

Thesis 123483
W482 Westfahl
c.1 An unconfined compression testing machine for marine sediments.